DRAFT
ENVIRONMENTAL IMPACT STATEMENT

COMMERCIAL LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE
RICHLAND, WASHINGTON

August 2000

Washington State Department of Health

WASHINGTON STATE DEPARTMENT OF ECOLOGY

September 13, 2000

To: Public Agencies and Persons with Interest in the Commercial Low-Level Radioactive Waste Disposal Site in Richland, Washington

In response to a February 14, 1997 State Environmental Protection Act (SEPA), Chapter 43.21C RCW, Determination of Significance, this draft Environmental Impact Statement (EIS) has been jointly prepared by the Washington State Department of Health and the Washington State Department of Ecology. The purpose of this draft EIS is to evaluate three pending actions at the commercial low-level radioactive waste (LLRW) disposal site in Richland, Washington. The three pending actions are:

1. Renewal of the US Ecology, Inc. (US Ecology) Washington State radioactive materials license for operation of the commercial LLRW disposal site.

2. Amendment of Chapter 246-249 WAC (Washington Administrative Code), establishing an annual upper limit of 100,000 cubic feet for diffuse Naturally Occurring or Accelerator Produced Radioactive Material (NARM) disposed at the commercial LLRW disposal site.

3. Approval of the July 1996 *Site Stabilization and Closure Plan* submitted by US Ecology to the Washington State Department of Health.

The three pending actions of License Renewal, NARM Acceptance, and Site Closure are separate but concurrent actions evaluated in one draft EIS. The three actions were evaluated together because each action was anticipated to affect the others. Each of the three actions is described below:

<u>License Renewal</u>

This pending action would approve the US Ecology radioactive materials license application and renew the license for an additional five years of operating the commercial LLRW disposal site. Two alternatives to license renewal are evaluated: denying the license, or renewing the license with operational enhancements. Denying the license would close the site and require generators within the states of Washington, Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Nevada, Colorado, and New Mexico, to store or dispose of their LLRW elsewhere. Key issues for license renewal are Washington's role in the shared responsibility of LLRW disposal, and the public health and environmental impacts of continued operation of the commercial LLRW disposal site.

NARM Acceptance

This pending action would amend Chapter 246-249 WAC to allow 100,000 cubic feet per year of diffuse NARM to be disposed at the commercial LLRW disposal site. This pending action is in response to a 1996 settlement agreement between the Washington State Department of Health and US Ecology that established an interim NARM limit of 100,000 cubic feet per year, and required future rulemaking to adopt a final limit. There are two alternatives to adopting the NARM limit of 100,000 cubic feet per year: a limit of 8,600 cubic feet per year, and a limit of 50,000 cubic feet per year. The key issue for this pending action is the impact of NARM waste on public health and the environment.

Site Closure

This pending action would approve the US Ecology 1996 Site Stabilization and Closure Plan, which would leave the waste in place and cover the site with a low-permeability cover. This pending action is in response to Chapter 246-250 WAC, which requires the commercial LLRW disposal site to have an approved closure plan. There are five conceptual designs and several scheduling alternatives to the US Ecology plan. The key issue for site closure is the long-term public health risks and environmental impacts predicted for a 10,000-year post-closure period.

The agencies have not proposed a preferred alternative for any of the three pending actions in this draft EIS. Selection of a preferred alternative will be done after public comment is received on this draft EIS. Public comment will be accepted for 45 days, beginning September 25, 2000.

For more information, please contact Nancy Darling, Project Manager, (360) 236-3244, or e-mail her at ned0303@doh.wa.gov.

Sincerely,

John Erickson, Director
Division of Radiation Protection
Washington Department of Health

Mike Wilson, Program Manager
Nuclear Waste Program
Washington Department of Ecology

FACT SHEET

TITLE: Draft Environmental Impact Statement for the Commercial Low-Level Radioactive Waste Disposal Site, Richland, Washington.

1. PROJECT DESCRIPTION

There are three pending actions under consideration at the commercial low-level radioactive waste disposal site (commercial LLRW disposal site). They are:

1. Renewal of the US Ecology, Inc., Washington State Radioactive Materials License for operation of the commercial LLRW disposal site.

2. Amendment of Chapter 246-249 WAC (Washington Administrative Code) establishing a 100,000 cubic foot per year upper limit for diffuse naturally occurring radioactive material (NARM) disposed at the commercial LLRW disposal site.

3. Approval of the July 1996 *Site Stabilization and Closure Plan* submitted by US Ecology, Inc. to the Washington Department of Health.

For each pending action, there is a No Action Alternative and several reasonable alternatives evaluated. A total of 11 alternatives are evaluated in this draft environmental impact statement (DEIS).

2. PROJECT PROPONENT

The Washington State Department of Health and the Washington State Department of Ecology are the project proponents for the three pending actions.

3. DATE OF IMPLEMENTATION

Implementation of the three pending actions or alternatives will begin upon approval of the Final Environmental Impact Statement (Final EIS). Approval of the Final EIS is expected no later than March 15, 2001.

4. LEAD AGENCIES

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Division of Radiation Protection
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PO Box 47827
Olympia, WA 98504-7827

Responsible Official: Mr. John Erickson, Division Director

Washington Department of Ecology
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PO Box 40117
Olympia, WA 98504-0117

Responsible Official: Mr. Mike Wilson, Program Manager

Contact Person: Ms. Nancy Darling, Project Manager,
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Fax: 360/236-2255
E-mail: nancy.darling@doh.wa.gov

5. REQUIRED LICENSES AND PERMITS

Radioactive Materials License WN-I019-2 – Issued to US Ecology, Inc. by Washington Department of Health

Site Use Permit G1004 issued by Washington Department of Ecology

Brokerage Permit B101 issued by Washington Department of Ecology

Radio License KNHU550 issued by Federal Communications Commission

6. AUTHORS AND PRINCIPAL CONTRIBUTORS

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7. DATE OF ISSUE

The DEIS date of issue is September 13, 2000. The DEIS may be posted on the Washington Department of Health and the Washington Department of Ecology websites prior to this date.

8. COMMENT PERIOD AND DUE DATE

The public comment period begins September 25, 2000. Comments must be received or postmarked no later than November 8, 2000. Send comments to Nancy Darling, Project Manager, at nancy.darling@doh.wa.gov, or at Washington State Department of Health, Division of Radiation Protection, Mail Stop 47827, Olympia, WA 98504-7827.

9. PUBLIC HEARINGS

Public hearings will be held in October 2000. The dates and locations will be announced.

10. DATE OF FINAL DECISION

The lead agencies have not determined the date of final decision. This decision is planned for no later than March 15, 2001.

11. FURTHER REVIEW

Each pending action or alternative will be subject to further review before implementation. License Renewal will be subject to WDOH review of license conditions; NARM Acceptance will be subject to rule adoption proceedings pursuant to the Administrative Procedures Act, RCW 34.05; and Site Closure will be subject to engineering and environmental reviews during the design and construction phase.

12. LOCATION OF TECHNICAL SUPPORT DOCUMENTS

Washington Department of Health
Division of Radiation Protection
7171 Cleanwater Lane, Bldg. 5
PO Box 47827
Olympia, WA 98504-7827

12. COST OF DEIS

An initial copy of the DEIS will be distributed, by request, at no cost. Additional copies may incur a cost.

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ACRONYMS

AEC	Atomic Energy Commission
ALARA	as low as reasonably achievable
DEIS	draft environmental impact statement
ECB	engineered concrete barriers
DEIS	environmental impact statement
GWSCREEN	a computer code
HAEIF	Hanford Area Economic Investment Fund
HMS	Hanford Meteorological Station
ICRP	International Council on Radiation Protection
LLRW	low-level radioactive waste
MCL	maximum contaminant level
MDC	maximum detection concentration
MEI	maximally exposed individual
MTCA	Model Toxics Control Act
N/A	not applicable
NARM	Naturally Occurring or Accelerator Produced Radioactive Material
U.S. NRC	U.S. Nuclear Regulatory Commission
PC&M	perpetual care and maintenance
PNNL	Pacific Northwest National Laboratory (formerly “PNL”)
RADTRAN	a computer code
RCRA	Resource Conservation and Recovery Act
RCW	Revised Code of Washington
SEPA	State Environmental Protection Act
SHPO	Site Historical Preservation Office
TEDE	total effective dose equivalent
TER	technical evaluation report
TLD	thermoluminescent dosimeter
TRV	Trojan Reactor Vessel
TWRS	Tank Waste Remediation System
UNSAT-H	a computer code
US Ecology	US Ecology, Inc.
U.S. DOE	U.S. Department of Energy
U.S. DOT	U.S. Department of Transportation
U.S. EPA	U.S. Environmental Protection Agency
U.S. NRC	U.S. Nuclear Regulatory Commission
WAC	Washington Administrative Code
WDOH	Washington State Department of Health
WISHA	Washington Industrial Safety and Health Act
WUTC	Washington Utilities and Transportation Commission

FOREWARD: RADIATION SOURCES AND RISK

This information is provided to help the reader understand radioactivity and its effects on health and the environment. Every individual is exposed to radiation on a daily basis. Sources of natural radiation include naturally occurring radioactive isotopes in the human body and in the earth's crust, naturally occurring radon gas, and cosmic radiation.   In addition to these unavoidable exposures, most individuals elect to receive "voluntary" exposures to radiation when they agree to x-rays, certain medical treatments, and airplane travel. Some building materials also contribute to voluntary radiation exposures. Some people are exposed to other less common man-made sources of radiation. These may include living close to a nuclear power plant or a radioactive waste disposal site, working with radioactivity, or being affected by an accident involving radioactive materials. Some common radiation terms are defined below.

Measurements Common to Radiation	
Name	**Definition**
Decay	The decrease in the amount of radioactive material with the passage of time, due to the spontaneous emission of radiation.
Half-life	The amount of time for half of a given quantity of a specific radioactive material to decay.
Curie	Unit of measurement for the rate of radioactive decay.
Millirem (mrem)	Unit of measurement used to quantify an individual's dose of radiation exposure.

i. Radiation Doses

The amount an individual is exposed to radiation is called a "dose" and is commonly measured in units of "millirems" (mrem). In this DEIS, unless specified otherwise, radiation doses are presented for the total effective dose equivalent (TEDE). The TEDE is the total dose, from the sum of both internal and external exposure. Internal exposure results from ingestion or inhalation of radioactive materials, while external exposure results from radiation emitted from a source external to the body.

The world's average annual dose to an individual from natural sources is 238 mrem/year. Contributions include 23 mrem from naturally occurring radioisotopes found in the human body, 46 mrem from naturally occurring radioisotopes found in the earth's crust, 39 mrem from cosmic radiation, and 130 mrem from exposure to natural radon. Assuming a 70-year life span, an individual would receive an average lifetime cumulative dose of about 17,000 mrem.

The annual dose to different individuals from natural sources varies greatly, often depending on where the person lives. Variations of a factor of two from the average are common, and variations of a factor of ten are not rare. The range of an individual's annual dose extends from about 100 mrem/year to about 2000 mrem/year. An individual's dose may be greater due to exposure to man-made sources of radiation. Some examples of doses from man-made sources are listed below.

Average Radiation Dose	
Sources	**Average Dose**
X-ray	5-300 mrem
Nuclear Medicine	250-1500 mrem
Cross-Country Airplane Flight	4 mrem
Nuclear Industry Worker	1000-15,000 mrem average lifetime
Closed Commercial Low-Level Radioactive Disposal Site	25 mrem/year (regulatory standard)

ii. Radiation Risk

Risk from exposure to radiation is defined as the probability that a person will be harmed by radiation. Most commonly, radiation risk refers to the probability of death from cancer. It is well established that very high radiation doses of about 400,000 mrem, administered at high dose rates, are fatal. It is also established that doses greater than about 10,000 to 20,000 mrem, administered at high dose rates, may cause cancer. At the lower doses and lower dose rates typically received by members of the public and radiation workers, there is no direct evidence that radiation causes harm.

Because there is no direct evidence that lower doses of radiation are harmful, public health risks at these lower doses are estimated based on health effects measured at much higher doses. It is often assumed there is a linear relationship between dose and risk, and that there is no threshold below which risk does not exist. This assumption is known as the Linear No Threshold (LNT) model, and is similar to models used to predict risk from other cancer-causing agents. Radiation protection agencies and organizations use the LNT. Risks estimated in this DEIS were based on the LNT model.

1.0 EXECUTIVE SUMMARY

1.1 Location and Site Description

Washington State hosts one of the nation's three commercial low-level radioactive waste disposal sites. The commercial LLRW disposal site is located in Benton County and is approximately 23 miles northwest of Richland, Washington. It is situated near the center of the 560 square mile United States Department of Energy (U.S. DOE) Hanford Site (Hanford) on approximately 100 acres of federal land leased to the state of Washington (see Figure 1.0). The commercial LLRW disposal site has been in operation since 1965 and is currently operated by US Ecology, Inc. (US Ecology). Access to the commercial LLRW disposal site is restricted and there are no permanent residences on or adjacent to the site. The Columbia River, located approximately 17 miles east, is the nearest significant surface water body. Groundwater depth is over 300 feet and the average precipitation is approximately 6 inches per year (Neitzel 1996). There are no domestic or municipal wells onsite or within several miles of the facility.

The commercial LLRW disposal site is located in an area of Hanford known as the "central plateau." The central plateau is an area of intensive waste management activities associated with U.S. government nuclear weapons production dating from the 1940's. On the central plateau, the "200 east" and "200 west" areas were the center for chemical processing for the production of plutonium. These areas contain several large underground tank farms, storage facilities and land disposal facilities.

The commercial LLRW disposal site practices conventional shallow-land burial of packaged waste into unlined trenches. The trenches are approximately 800 feet long, 150 feet wide and 45 feet deep. In addition to the trenches, five underground storage tanks were installed for treatment and disposal of liquid low-level radioactive resin wastes.[1] There are currently three open operating trenches and 20 filled trenches including one nuclear reactor vessel and three emptied underground tanks. The filled trenches have been covered with at least five feet of site soils. At current rates of waste disposal, fewer than ten more trenches will be filled by the proposed closure date of year 2056. At the current rates of disposal, only approximately 60% of the total available disposal capacity at the 100-acre commercial disposal site will be used.

Several types of waste have been disposed at the commercial LLRW disposal site since 1965. Waste types include low-level radioactive, naturally occurring and accelerator-produced material (NARM), non-radioactive hazardous, and mixed waste (radioactive waste having a hazardous component). Since 1985, only low-level radioactive waste and NARM have been allowed for disposal. Low-level radioactive waste is waste such as trash, clothing, tools, hardware, and equipment that has been contaminated by

[1] Two of these tanks were removed and the remaining three tanks were emptied and closed in 1985.

radioactive substances. The low-level radioactive waste at the commercial LLRW disposal site is typically generated by five sources. These sources are nuclear power plants, industrial users, government and military organizations, academic institutions, and the medical community. NARM waste includes, but is not limited to, pipe scale from oil and gas pipelines, soils from cleanup of mineral processing sites, and measuring devices and gauges.

Groundwater contamination, from past U.S. DOE activities on the central plateau, has been well documented (PNNL 1999). Radionuclides contaminating the groundwater include tritium, cobalt 60, strontium 90, technetium 99, iodine 129, cesium 137, and plutonium and uranium isotopes. Several of these plumes are expanding and moving towards the commercial LLRW disposal site (PNNL 1999). U.S. DOE, under the Hanford Federal Facility Agreement and Consent Order with the Washington State Department of Ecology (Department of Ecology) and the U.S. Environmental Protection Agency (EPA), is in the process of remediating the contaminated sites at Hanford (Department of Ecology 1989). No orders for remedial actions apply to the commercial LLRW disposal site at this time.

Figure 1: Map of Hanford

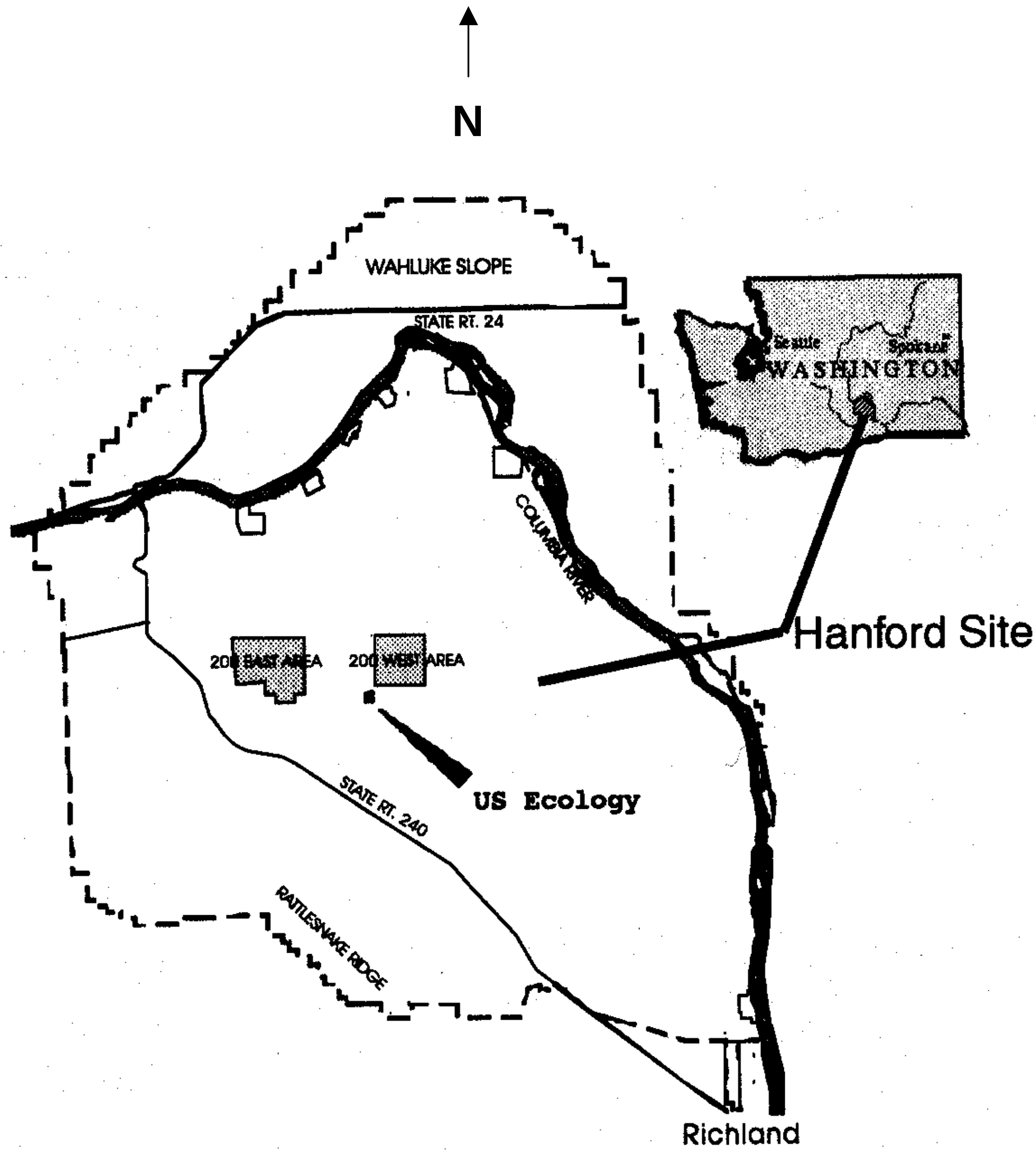
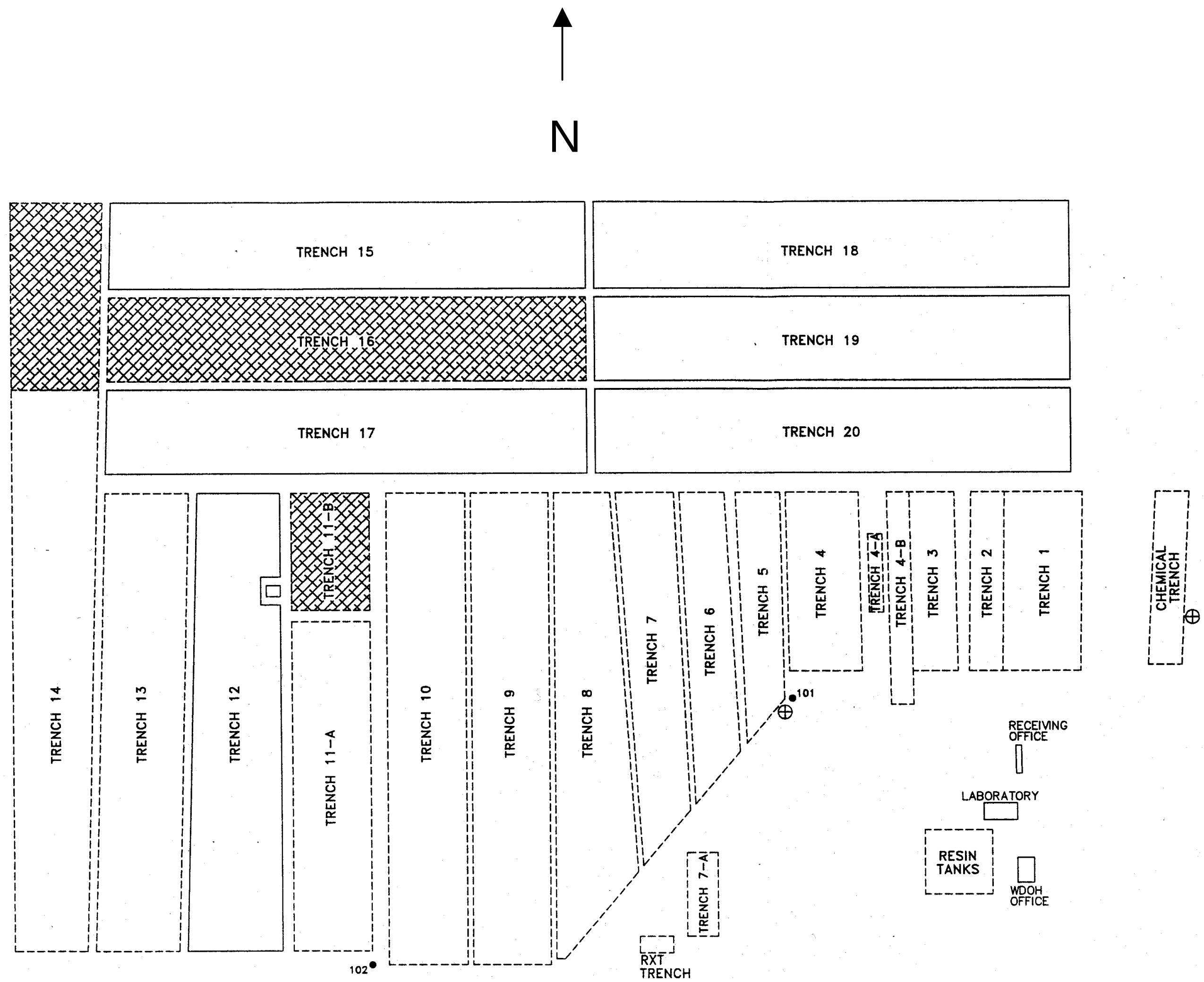


Figure 2: Map of Commercial LLRW Disposal Site



1.2 Purpose and Need of Pending Actions

The purpose of this DEIS is to inform the public, agencies and jurisdictions, and the tribes of the potential impacts of three pending actions at the commercial LLRW disposal site. The three pending actions are:

1. Renewal of the US Ecology Washington State Radioactive Materials License (US Ecology License) to operate the commercial LLRW disposal site.

2. Amendment of Chapter 246-249 WAC (Washington Administrative Code) establishing a 100,000 cubic foot per year limit for diffuse naturally occurring radioactive material (NARM) disposed at the commercial LLRW disposal site.

3. Approval of the July 1996 *Site Stabilization and Closure Plan* submitted by US Ecology.

The Washington State Environmental Policy Act (SEPA), Chapter 43.21C RCW (Revised Code of Washington), mandates an environmental review for actions potentially having a significant adverse environmental impact. A 1997 SEPA review considered the potential summed impacts from all three actions, and a determination of significance (DS) was issued on February 14, 1997 (WDOH 1997). As a result of the DS, the Washington Department of Health (WDOH) and the Washington Department of Ecology (Department of Ecology) jointly prepared this DEIS. Public scoping meetings were held in Seattle, Spokane, and Richland in the spring of 1997. Written and oral comments received during the public comment period helped determine the scope of this DEIS (WDOH 1998).

The following three sections briefly describe the history and need for License Renewal, NARM Acceptance, and Site Closure at the commercial LLRW disposal site.

1.2.1 License Renewal

The commercial LLRW disposal site was first licensed in 1964 and began receiving waste in 1965. As the site operator, US Ecology is required to submit a license renewal application to the WDOH every five years. WDOH performs a comprehensive review of the application, and upon approval, issues a new license effective for another five years. Two previous SEPA reviews for relicensing resulted in determinations of non-significance.[2]

The current application for relicensing was submitted to WDOH on January 7, 1997. The SEPA threshold determination for the 1997 relicensing application resulted in a determination of significance primarily because the US Ecology License application was reviewed as part of a package of all three pending actions. During the DEIS process,

[2] Previous SEPA threshold determinations for relicensing the site were done in 1986 and 1991.

the current US Ecology License remains in effect. Waste disposal practices included in the current US Ecology License are described in Appendix 1.

1.2.2 NARM Acceptance

NARM is defined as “any naturally occurring or accelerator produced radioactive material except byproduct, source, or special nuclear material”.[3] NARM is either diffuse or discrete. Diffuse NARM is low activity, but usually high in volume. Discrete NARM is high activity, but very low in volume. Section 2.3.3 discusses the origins and characteristics of NARM. In this DEIS, all discussion of NARM Acceptance pertains to diffuse NARM.

Prior to 1986, no distinction was made between NARM and low-level radioactive waste. In 1986, WDOH adopted the first Washington State regulation addressing diffuse NARM volumes. Although no maximum limit was placed on NARM disposal, WAC 246-249-080 required generators of 1,000 cubic feet per year (ft^3/year) or more of diffuse NARM to obtain WDOH approval prior to shipping the waste to the commercial LLRW disposal site. The purpose of this regulation was to ensure that disposal of NARM did not jeopardize the disposal capacity needed for low-level radioactive waste at the commercial LLRW disposal site.

In 1991, WDOH observed substantial increases in the amount of NARM disposed at the commercial LLRW disposal site. Faced with the dilemma of making judgments and decisions about the allowable quantities of NARM, WDOH formed the NORM Task Force[4] (NORM Task Force 1993). The NORM Task Force evaluated the current WDOH policy and regulations and made the following recommendations:

1. There should be an annual cap on the total amount of NARM accepted at the site.

2. The NARM limit requiring WDOH review and approval should be raised to 10,000 ft^3/year.

3. A policy review on NARM should be done every five years.

Subsequently, WDOH proposed an amendment to WAC 246-249-080 to limit diffuse NARM at the commercial LLRW disposal site to 8,600 ft^3/year, with individual generators limited to no more than 1,000 ft^3/year. WDOH selected 8,600 ft^3/year, based on projections of future NARM volumes. The amended regulation became effective July 22, 1995.

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[3] In the past, the acronym “NORM” was used to define naturally occurring radioactive material, and the term "NARM” was used to define naturally accelerated radioactive material. Since then, WDOH has adopted the term “NARM” to describe both types of waste.

[4] The NORM Task Force membership included agency staff, waste generators, and environmental stakeholders.

In September 1995, US Ecology filed a lawsuit against WDOH, alleging that the new limits lacked public health justification. In May 1996, WDOH and US Ecology negotiated a settlement agreement where WDOH agreed to initiate rulemaking to consider a 100,000 cubic foot limit per year, and US Ecology agreed to dismiss the lawsuit.[5] The court also imposed a 100,000-ft^3/year limit during the rulemaking proceedings. The 1997 SEPA environmental review determined that a DEIS was the appropriate first step in evaluating a 100,000-ft^3/year NARM limit. Future rulemaking for NARM will be based on the conclusions of this DEIS.

1.2.3 Site Closure

The commercial LLRW disposal site is located on land leased by Washington State from the U.S. DOE. This lease expires on September 9, 2063. At that time, the site must permanently close or the lease must be extended. WDOH expects construction for the closure to take five years and has proposed the year 2056 for disposal operations to cease and closure to begin.

Chapter 246-250 WAC requires the commercial LLRW disposal site to have an approved closure plan to continue operations. An approved closure plan must address cover design, closure schedule, institutional controls, environmental monitoring and cost estimates. The closure plan must also include a performance assessment that shows the proposed closure will meet all regulatory standards.

US Ecology submitted the first closure plan in 1983. Subsequent closure plans were submitted in 1987 and 1990. In each case, WDOH required amendments to the plan. After extensive coordination with WDOH and the Department of Ecology, US Ecology submitted the *1996 US Ecology, Inc. Site Stabilization and Closure Plan* (US Ecology Closure Plan) for approval (US Ecology 1996). The 1997 SEPA review determined a DEIS was appropriate for evaluating the US Ecology Closure Plan. In a separate evaluation, WDOH completed a Technical Evaluation Report that determined the 1996 US Ecology Closure Plan met the minimum regulatory requirements for closure of the commercial LLRW disposal site (Dunkelman 1999).[6]

1.3 Summary of Pending Actions and Alternatives

Several alternatives have been identified for each pending action. The purpose of the alternatives is to provide a comparison with the pending action in terms of public health risk, environmental impacts, and other considerations. Table 1 briefly describes each pending action and the alternatives to that action. Section 3.0 describes each pending action and alternative in more detail.

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[5] The 100,000-ft^3/year NARM volume was based on negotiations between WDOH and US Ecology.

[6] This DEIS has a different focus than the TER and it considers, for the purpose of comparison of alternatives, hypothetical impacts on sensitive populations such as Native Americans and children. For this reason, this DEIS may recommend different closure actions than the TER.

Table 1: Pending Actions and Alternatives

Pending Action and Alternatives	Description
1. Pending Action: Renew Radioactive Materials License	WDOH would approve the US Ecology License application to continue operating the commercial LLRW disposal site for 5 more years. This action would maintain the current license requirements with revisions as necessary.
No Action Alternative: Deny License Renewal	WDOH would deny the US Ecology License application to continue operation of the commercial LLRW disposal site. Upon denial, the site would cease operations and begin closure.
Alternative 1: Renew License with Operational Enhancements	WDOH would approve the US Ecology License and would negotiate the inclusion of 18 operational enhancements into the license. These enhancements are designed to further protect public heath, worker safety, and the environment.
2. Pending Action: Establish acceptance limit of 100,000 ft^3/year for diffuse NARM	WDOH would amend Chapter 246-249 WAC to allow US Ecology to accept up to 100,000 ft^3/year of diffuse NARM waste for disposal at the commercial LLRW disposal site. This action also includes an annual rollover provision for those years when less than 100,000 ft^3/year of NARM is disposed. The 100,000-ft^3/year limit is currently in effect pursuant to a settlement agreement between US Ecology and Washington State.
No Action Alternative: Establish acceptance limit of 8,600 ft^3/year for diffuse NARM	WDOH would reinstate the NARM Acceptance limit of 8,600 ft^3/year in Chapter 246-249 WAC. This regulatory limit was previously adopted by WDOH and then stayed as a result of the settlement agreement that established the 100,000-ft^3/year NARM volume limit. There is no rollover provision in this alternative.
Alternative 1: Establish acceptance limit of 36,700 ft^3/year for diffuse NARM	WDOH would amend Chapter 246-249 WAC to establish a NARM Acceptance limit of 36,700 ft^3/year. This volume is based on the average disposed volumes of NARM waste from 1992 to 1995. There is no rollover provision in this alternative.
3. Pending Action: Site Closure	For evaluation, Site Closure has been divided into review of the US Ecology Cover design and review of the US Ecology Proposed Closure Schedule.
3a. Pending Action: Proposed US Ecology Closure Cover Design	WDOH would approve the US Ecology Proposed Cover as described in the US Ecology 1996 Closure Plan. The US Ecology Proposed Cover was designed in coordination with WDOH and Department of Ecology. This cover is a multi-layer design, approximately 16 feet thick, with a 12-inch thick bentonite clay low-permeability barrier. The US Ecology Proposed Cover was evaluated for a closure date of year 2056. This US Ecology Proposed Cover was also evaluated as part of the Filled Site Alternative.
No Action Alternative: Site Soils Cover	The conceptual Site Soils Cover is an 8 to 11 foot thick mound of site soils. For evaluation purposes, it was assumed that a Site Soils Cover would only be used if the commercial LLRW disposal site were closed immediately and without an approved closure plan. Therefore, this cover was evaluated for a site closure date of year 2000.
Alternative 1: Thick Homogenous Cover	The conceptual Thick Homogenous Cover is a two-layer cover that is approximately 16 feet thick. It has a 60-inch thick silt loam layer

Pending Action and Alternatives	Description
	underlain by site soils. This cover design does not include a low-permeability barrier. The Thick Homogenous Cover was evaluated for a closure date in the year 2056.
Alternative 2: Enhanced Cover	There are three variations of the conceptual Enhanced Cover design. These covers are multi-layer covers with 60-inch silt loam layers and low-permeability barriers. The Enhanced Covers vary by the type of low-permeability barrier contained in the cover. The three enhanced covers evaluated in this DEIS are: • Enhanced Asphalt Cover • Enhanced Synthetic Cover • Enhanced Bentonite Cover The names of these covers identify the type of low-permeability barrier included in the conceptual design. All of these covers are evaluated for closure in the year 2056. In addition, the Enhanced Bentonite Cover is evaluated for closure in the year 2000.
3b. Pending Action: Proposed US Ecology Closure Schedule	WDOH would approve the US Ecology Proposed Closure Schedule that closes seven trenches immediately and the remainder of the site in year 2056.
No Action Alternative: “No Early Construction”	The “No Early Construction” Schedule closes the entire site in the year 2056 with no early closure of filled trenches.
Alternative 1: Prototype Schedule	The Prototype Schedule closes one or two filled trenches early and the remainder of the site in the year 2056.
Alternative 2: Close-as-you-go Schedule	The Close-as-you-go Schedule closes trenches as they are filled, or soon after.
Filled Site Alternative	The Filled Site Alternative is different than all other alternatives in that it includes all three actions. This alternative assumes the commercial LLRW disposal site is filled to capacity through either an extended operating period or by accepting significantly higher volumes of waste through the year 2056. In evaluating this alternative, it was assumed the NARM Acceptance limit was 36,700 ft^3/year and the site is closed with the US Ecology Proposed Cover and the US Ecology Proposed Closure Schedule.

1.4 Summary and Comparison of Impacts

Tables 2, 3, 4, and 5 summarize the impacts, mitigation measures, and significant unavoidable adverse impacts for License Renewal, NARM Acceptance, and Site Closure. For display purposes, the Filled Site Alternative is included with License Renewal in Table 2. Tables 2, 3, 4, and 5 present a brief summary of impacts and should be used with reference to the discussion of impacts presented in Section 4.0.

Table 2: License Renewal: Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
OPERATIONAL RISKS			
Impacts Normal operational risks associated with waste disposal activities can be expected. These include slips, falls, and sprains. No unacceptable radiation exposure to the public or site workers is expected from operations.	No operational risks because site is no longer operating.	Enhanced practices may increase worker dose due to increased waste handling.	Higher waste volumes will increase normal operating risks.
Mitigation Measures Standard Washington industrial safety practices will be used during operations.	None suggested	Evaluate enhanced operational practices to minimize worker safety risks.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
TRANSPORTATION RISKS			
Impacts Cancer risk is less than 1.0×10^{-8} for individuals from transporting waste to the commercial LLRW disposal site.	Zero risk to individuals because there would be no more transportation of waste to the site.	Enhanced inspections of packaging may reduce low risk even further.	Higher risk from increased transportation associated with more waste disposal. Risk was not quantitatively calculated for this alternative.
Mitigation Measures None suggested	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
COVER CONSTRUCTION RISKS			
Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
LONG-TERM PUBLIC HEALTH			
Impacts Although License Renewal will increase the dose to individuals during the 10,000- year post-closure period, it is a minor impact on public health. License Renewal is predicted to result in a 20% increase to the maximum dose of a person living adjacent to the commercial LLRW disposal site. For the onsite intruder, renewing the license is expected to increase the future dose by 33%. The individual dose is dependent on site closure and NARM volumes.	Individuals will still receive a dose during the 10,000-year post closure period but it will be less than the dose associated with relicensing the site. The individual dose is dependent on site closure.	Renewing the license with operational enhancements will likely result in a smaller dose than the pending action. This expected dose reduction was not calculated. The individual dose is dependent on site closure and NARM volumes.	Filling the site to capacity is predicted to increase the maximum dose to the offsite individual by 27%. For the onsite intruder, filling the site is predicted to increase the dose by 67% and cause the onsite intruder dose to exceed the 500-mrem/year guidance level.
Mitigation Measures Select a Closure Cover Design with high performance and high reliability. Select a Closure Cover Schedule that maximizes early isolation of waste. Select a NARM Acceptance level that will minimize dose to the onsite intruder. Use enhanced institutional controls to deter onsite intruders. Use enhanced disposal practices for NARM waste including a dedicated trench and deeper burial. Immediately construct a low-permeability interim cover over all filled trenches. Conduct performance and reliability monitoring of early constructed covers.	Select a Closure Cover Design with high performance and high reliability Use enhanced institutional controls to deter onsite intruders.	Same as pending action.	Same as pending action.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
Use enhanced environmental monitoring to validate groundwater modeling assumptions and conclusions. **Significant Unavoidable Adverse Impacts** None identified.	 Same as pending action.	 Same as pending action.	 Exceeds the 500-mrem/year guidance level for the onsite intruder.
EARTH **Impacts** Continued impacts to surface soils at the commercial LLRW disposal sites are expected. Impacts include minor surface soil contamination, reduced water storage capacity, and reduced soil productivity. **Mitigation Measures** Select a closure cover design with high silt content in upper 5 feet of cover. Immediate construction of a low-permeability interim or final cover over filled trenches to mitigate increased infiltration associated with disturbed soil. **Significant Unavoidable Adverse Impacts** None identified	 No additional impacts over those impacts already present. Same as pending action. Same as pending action.	 Same as pending action. Same as pending action. Same as pending action.	 Greater soils disturbance predicted due to increased waste disposal. Same as pending action. Same as pending action.
WATER **Impacts** Within 10,000 years post-closure, the groundwater is predicted to exceed the 50 pCi/L (picocuries per liter) gross beta standard in the Ground Water Quality Standards (Chapter 173-201 WAC). Gross Beta is expected to reach a maximum activity of 101 to	 Denying the license will not add any additional gross beta to the groundwater over what is predicted with existing waste volumes. Gross Beta activity from existing waste volumes are	 Same as pending action.	 Filling the site is predicted to result in a gross beta activity in the groundwater of 216 pCi/L. This increase is 36 pCi/L over the pending action.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
220 pCi/L depending on what cover design is used for closure. The gross beta standard will be exceeded whether or not the site is relicensed. Renewal of the license is predicted to increase gross beta activity in groundwater 6 pCi/L (6%). **Mitigation Measures** Resample for radionuclides detected in groundwater to determine contributions, if any, from the commercial LLRW disposal site. Expand annual environmental groundwater sampling to include beta emitters detected in the US Ecology Site Investigation. Select a closure cover design with high performance and high reliability. Select a closure cover schedule that maximizes early isolation of waste. Immediately construct a low-permeability interim cover over all filled trenches. **Significant Unavoidable Adverse Impacts** Exceeding the gross beta standard for groundwater during 10,000 year post-closure period.	predicted to reach a maximum of 95 to 220 pCi/L depending on what cover design is used for closure. Resample for radionuclides detected in groundwater to determine contributions, if any, from the commercial LLRW disposal site. Expand annual environmental groundwater sampling to include beta emitters detected in the US Ecology Site Investigation. Select a closure cover design with high performance and high reliability. Same as pending action.	Same as pending action. Same as pending action.	Same as pending action. Same as pending action.
AIR **Impacts** License Renewal will result in continued generation of dust from normal waste disposal activities. [Note: Long-term radiological impacts to air are discussed in this DEIS as a public health issue and are not included in this	None identified	This alternative includes enhanced practices to reduce dust generation.	Increased dust generation due to excavation of more trenches and greater volumes of waste disposed.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
section."] **Mitigation Measures** Continue current dust control methods including the use of soil fixatives and increased vegetation. **Significant Unavoidable Adverse Impacts** None identified	 None identified Same as pending action.	 Same as pending action (already included in alternative). Same as pending action.	 Same as pending action. Same as pending action.
ECOLOGY **Impacts** No further impacts to the shrub-steppe habitat have been identified from License Renewal. However; relicensing the commercial disposal site will delay the return of the habitat that is already disturbed. **Mitigation Measures** Protect undisturbed 15 acres in northwest corner of commercial LLRW disposal site. Select a final cover with high silt loam content to encourage re-growth of the shrub-steppe habitat. Plant selected cover with native species. Select a closure schedule alternative that includes early construction of the final cover. **Significant Unavoidable Adverse Impacts** None identified	 None identified Select a final cover with high silt loam content to encourage re-growth of the shrub-steppe habitat. Plant selected cover with native species. Same as pending action.	 Same as pending action. Same as pending action. Same as pending action.	 Same as pending action. Protect undisturbed 15 acres in northwest corner of commercial LLRW disposal site. Plant selected cover with native species. Same as pending action.
CULTURAL RESOURCES **Impacts** Relicensing the site will continue to impact	 No further impacts.	 Same as pending action.	 Additional impacts to tribal

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
tribal cultural resources such as the wildlife, soil, vegetation, and groundwater through continued waste disposal and disturbance of the environment. **Mitigation Measures** Protect undisturbed 15 acres in NW corner. Use enhanced practices for NARM disposal including a dedicated trench and deeper burial of NARM waste. Select a final cover design with high performance and high reliability. Immediately construct a low-permeability interim cover over all filled trenches. Select a closure schedule alternative that provides early waste isolation. Plant cover with native species. Continue consultations with tribal governments. Continue consultation with the State Historic Preservation Office. **Significant Unavoidable Adverse Impacts** Impacts to tribal cultural resources.	Protect undisturbed 15 acres in NW corner. Select a cover design with high performance and high reliability. Plant cover with native species. Continue consultations with tribal governments. Continue consultation with the State Historic Preservation Office. Impacts to tribal cultural resources but less than pending action.	Same as pending action. Impacts to tribal cultural resources but less than pending action.	cultural resources due to increased waste disposal. Same as pending action. Impacts to tribal cultural resources but greater than pending action.
LAND USE **Impacts** None identified	Same as pending action.	Same as pending action.	Potential conflict with U.S. DOE Comprehensive Land

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
			Use Plan.
Mitigation Measures None suggested	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Potential conflict with U. S. DOE Comprehensive Land Use Plan.
CATASTROPHIC EVENTS			
Impacts Potential local ponding during rain on frozen ground and increased waste subsidence associated with earthquakes.	Same as pending action.	Same as pending action but this alternative has enhanced stormwater management to minimize ponding and reduction of void spaces in and between the waste to reduce subsidence.	Same as pending action.
Mitigation Measures Enhanced stormwater management and further reduction of void space in the waste and between the waste packages.	Enhanced stormwater management.	None identified – enhanced practices already part of alternative.	Enhanced stormwater management and further reduction of void space in the waste and between the waste packages.
Significant Unavoidable Adverse Impacts Some subsidence is likely due to earthquakes.	Same as pending action.	Same as pending action.	Same as pending action.
SOCIOECONOMIC			
Impacts Renewing the license and continued operation of the commercial LLRW disposal site will have the following impacts: Continued employment of 24 persons. Continued local revenue.	Denying the US Ecology License and closing the site will have the following impacts: Loss of approximately 24 jobs in local community.	Renewing the license with enhanced license requirements will increase some costs to waste generators.	Same as pending action.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
Continued contributions to Perpetual Care and Maintenance Fund. Continued in-state disposal capacity for low-level waste. Some increased wear on public roads from trucks carrying waste shipments.	Loss of further contributions to Perpetual Care and Maintenance Fund. Loss of further contributions to the Closure Fund. Loss of local revenues estimated to be $14 million to Benton county. Loss of revenue to the Hanford Area Economic Investment Fund estimated at $25 million. Loss of disposal capacity and increased disposal costs for low-level waste generators in Washington State.		
Mitigation Measures None suggested	Provide job placement services for persons who lose employment.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Loss of local revenue. Loss of in-state low-level waste disposal capacity. Loss of future contributions to Perpetual Care and Maintenance Fund.	Same as pending action.	Same as pending action.
CUMULATIVE EFFECTS **Impacts** Contributions to the cumulative effect from	Less contribution to the	Contributions to the cumulative	Contributions to the cumulative

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
License Renewal include all impacts listed under long-term health impacts, earth, water, air, ecology, cultural resources, and land use. **Mitigation Measures** All mitigation measures listed in this column. **Significant Unavoidable Adverse Impacts** All significant unavoidable adverse impacts listed in this column.	cumulative effect than the pending action except for greater contributions to the socioeconomic cumulative effect. All mitigation measures listed in this column. All significant unavoidable adverse impacts listed in this column.	effect from Enhanced License Renewal are likely less than the pending action and include all impacts listed under long-term health impacts, earth, water, air, ecology, cultural resources, and land use. All mitigation measures listed in this column. All significant unavoidable adverse impacts listed in this column.	effect from the Filled site Alternative are greater than the pending action and include all impacts listed under long-term health impacts, earth, water, air, ecology, cultural resources, and land use. All mitigation measures listed in this column. All significant unavoidable adverse impacts listed in this column.
ENVIRONMENTAL JUSTICE **Impacts** Slightly higher impacts to Native American Community compared to rural resident community. **Mitigation Measures** All mitigation measures listed in this column. **Significant Unavoidable Adverse Impacts** None identified	Same as pending action. All mitigation measures listed in this column. None identified	Same as pending action. All mitigation measures listed in this column. None identified	Same as pending action. All mitigation measures listed in this column. None identified
US ECOLOGY SITE INVESTIGATION **Impacts** None identified	Denying the license and closing the site immediately may impede future environmental monitoring during the Phase 3 of the US Ecology Site Investigation.	Same as pending action.	Same as pending action.

Pending Action – Renew the US Ecology Radioactive Materials License	No Action Alternative-- Deny License	Alternative 1—Renew License with Operational Enhancements	Filled Site Alternative
Mitigation Measures None suggested	Complete Phase 3 Investigation before closing the commercial LLRW disposal site or design Phase 3 around Site Closure.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Delaying closure to accommodate Phase 3 will result in delayed waste isolation.	Same as pending action.	Same as pending action.
COSTS AND SURETY			
Impacts Increases cover costs but provides opportunity to increase both the Closure Fund and the Perpetual Care and Maintenance Fund.	Reduces cover costs but decreases growth of Perpetual Care and Maintenance Fund and the Closure Fund. This growth reduction eliminates closing the site with the Proposed US Ecology Cover or any of the Enhanced Cover Alternatives.	Same as pending action.	Provides greater opportunity for growth of Perpetual Care and Maintenance Fund and Closure Fund and allow funding of all cover design alternatives.
Mitigation Measures None suggested	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.

Table 3: NARM Acceptance Levels: Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts[7]

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
OPERATIONAL RISKS **Impacts** Normal operational risks associated with waste disposal activities can be expected. These include slips, falls, and sprains. No unacceptable radiation exposure to site workers or the public expected from disposal of NARM. **Mitigation Measures** Standard Washington industrial safety practices will be used during operations. **Significant Unavoidable Adverse Impacts** None identified	Fewer operational risks expected due to less waste handling. Same as pending action. Same as pending action.	Fewer operational risks expected due to less waste handling. Same as pending action. Same as pending action.
TRANSPORTATION RISKS **Impacts** Individual cancer risk less than 1.0×10^{-9} from transportation of NARM to site. **Mitigation Measures** None suggested **Significant Unavoidable Adverse Impacts** None identified	Less risk than pending action. Same as pending action. Same as pending action.	Less risk than pending action. Same as pending action. Same as pending action.
COVER CONSTRUCTION RISKS **Impacts** None identified	Same as pending action.	Same as pending action.

[7] Impacts of NARM Acceptance include impacts for total annual volumes of all low-level waste disposed at the commercial LLRW disposal site.

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
LONG-TERM PUBLIC HEALTH **Impacts** Long-term health impacts from NARM during the 10,000-year post-closure period are primarily from breathing radon gas that has been concentrated in a basement or a sweatlodge constructed on the commercial LLRW disposal site. Long-term impacts from NARM to persons living adjacent to the site are predicted to be minimal. Impacts to the onsite intruder from 100,000 ft^3/year low-level radioactive waste plus 100,000 ft^3/year of NARM range from 120 mrem/year to 1000 mrem/year depending on the closure date and cover design. The onsite intruder dose is predicted to exceed the 500-mrem/year guidance value for the Site Soils Cover, Thick Homogenous Cover and Enhanced Synthetic Cover.	Impacts to the onsite intruder 100,000 ft^3/year low-level radioactive waste plus 8,600 ft^3/year of NARM range from 81 mrem/year to 930 mrem/year depending on the closure date and cover design. Site Soils Cover exceeds the onsite intruder 500-mrem/year guidance value.	Impacts to the onsite intruder from 100,000 ft^3/year low-level radioactive waste plus 36,700 ft^3/year of NARM range from 93 mrem/year to 950 mrem/year depending on the closure date and cover design. Site Soils Cover exceeds onsite intruder 500-mrem/year guidance value.
Mitigation Measures Select a Closure Cover Design with a high performance and high reliability low-permeability barrier such as the Asphalt Enhanced Cover, US Ecology Proposed Cover or Enhanced Synthetic Cover. Select a Closure Cover Schedule that maximizes early isolation of the waste. Use enhanced institutional controls to deter onsite intruders. Use enhanced disposal practices for NARM waste including a dedicated trench and deeper burial. Immediately construct a low-permeability interim cover over all filled trenches. Conduct performance monitoring of early constructed covers. Conduct enhanced environmental monitoring to validate	Same as pending action.	Same as pending action.

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
groundwater modeling assumptions and conclusions. **Significant Unavoidable Adverse Impacts** Greater than 500 mrem/year dose for the onsite intruder from 100,000 ft^3/year low-level radioactive waste plus 100,000 ft^3/year of NARM predicted for the Site Soils Cover, Thick Homogenous Cover, Enhanced Synthetic Cover, and Filled Site Alternative.	Greater than 500 mrem/year dose for the onsite intruder from 100,000 ft^3/year low-level radioactive waste plus 8,600 ft^3/year of NARM predicted for the Site Soils Cover.	Greater than 500 mrem/year dose for the onsite intruder from 100,000 ft^3/year low-level radioactive waste plus 36,700 ft^3/year of NARM predicted for Site Soils Cover and Filled Site Alternative.
EARTH **Impacts** Higher volumes of NARM disposal may require additional trench construction resulting in increased soil disturbance. **Mitigation Measures** None suggested **Significant Unavoidable Adverse Impacts** None identified	None identified Same as pending action. Same as pending action.	Same as pending action. Same as pending action. Same as pending action.
WATER **Impacts** None identified	Same as pending action.	Same as pending action.
AIR **Impacts** NARM waste primarily impacts long-term onsite air quality through radon. In this DEIS, long-term radiological impacts to air are included in impacts to long-term public health and are not included in this section.	Same as pending action.	Same as pending action.
ECOLOGY **Impacts** No further impacts to the shrub-steppe habitat have been identified from the disposal of NARM waste.	Same as pending action.	Same as pending action.

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
CULTURAL RESOURCES **Impacts** NARM disposal will impact the post-closure use of sweat lodges by Native Americans living onsite. A sweatlodge will concentrate any radon gas that is present. NARM disposal will also continue to impact tribal cultural resources such as the wildlife, soil, vegetation, and groundwater through continued waste disposal and disturbance of the environment. **Mitigation Measures** Protect undisturbed 15 acres in NW corner. Use enhanced practices for NARM disposal, including a dedicated trench and deeper burial of NARM waste. Select a cover design with a high performance low-permeability barrier and high reliability. Select a closure schedule alternative that provides early waste isolation. Plant cover with native species. Continue consultations with tribal governments. Continue consultation with the State Historic Preservation Office. **Significant Unavoidable Adverse Impacts** Impacts to tribal cultural resources.	Same as pending action but less impact due to less NARM volumes. Same as pending action. Same as pending action.	Same as pending action but less impact due to less NARM volumes. Same as pending action. Same as pending action.
LAND USE **Impacts** None identified	Same as pending action.	Same as pending action.

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
CATASTROPHIC EVENTS **Impacts** None identified	 Same as pending action.	 Same as pending action.
SOCIOECONOMIC **Impacts** Provides maximum revenues from NARM to local government and the Perpetual Care and Maintenance Fund. Annual revenue would be $200,000 to Benton County and $450,000 to the Hanford Area Economic Investment Fund. Lifetime revenue to the Perpetual Care and Maintenance Fund is $9,800,000. Some increased wear on public roads from trucks carrying waste shipments. Disposal of 100,000 cubic feet per year of NARM will have no impact on disposal capacity for projected future levels of low-level radioactive waste. **Mitigation Measures** None suggested **Significant Unavoidable Adverse Impacts** None identified	 Provides minimum revenues from NARM to local government and the Perpetual Care and Maintenance Fund. Annual would be approximately $17,200 to Benton County and $38,700 to the Hanford Area Economic Investment Fund. Lifetime revenue to the Perpetual Care and Maintenance Fund is $842,800. Less wear on public roads than pending action from truck traffic. Same as pending action. Same as pending action.	 Provides moderate revenues from NARM to local government and the Perpetual Care and Maintenance Fund. Annual revenue would be approximately $73,400 to Benton County and $165,150 to the Hanford Area Economic Investment Fund. Lifetime revenue to the Perpetual Care and Maintenance Fund is $3,600,000. Less wear on public roads than pending action from truck traffic. Same as pending action. Same as pending action.
CUMULATIVE EFFECTS **Impacts** Contributions to the cumulative effect from NARM include all impacts listed in this column. **Mitigation Measures** All mitigation measures listed in this column. **Significant Unavoidable Adverse Impacts** All significant unavoidable adverse impacts listed in this column.	 Contributions to the cumulative effect from NARM include all impacts listed in this column. All mitigation measures listed in this column. All significant unavoidable adverse impacts listed in this column.	 Contributions to the cumulative effect from NARM include all impacts listed in this column. All mitigation measures listed in this column. All significant unavoidable adverse impacts listed in this column.

Pending Action – Establish NARM Acceptance Volume of 100,000 ft^3/year with a Rollover Provision.	No Action Alternative—Establish NARM Acceptance Volume of 8,600 ft^3/year	Alternative 1— Establish NARM Acceptance Volume of 36,700 ft^3/year
ENVIRONMENTAL JUSTICE **Impacts** Impacts are discussed as part of Site Closure in Table 4.	 Same as pending action.	 Same as pending action.
US ECOLOGY SITE INVESTIGATION **Impacts** None identified	 Same as pending action.	 Same as pending action.
COSTS AND SURETY **Impacts** NARM disposal contributes to the Perpetual Care and Maintenance Fund and would contribute to the Closure Fund if those fees were reinstated. More contributions to these funds mean greater surety. **Mitigation Measures** None suggested **Significant Unavoidable Adverse Impacts** None identified	 Same as pending action but less contribution to Perpetual Care and Maintenance Fund due to less volume. Same as pending action. Same as pending action.	 Same as pending action but less contribution to Perpetual Care and Maintenance Fund due to less volume. Same as pending action. Same as pending action.

Table 4: Site Closure – Conceptual Cover Design: Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
OPERATIONAL RISKS **Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.
TRANSPORTATION RISKS **Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.
COVER CONSTRUCTION RISKS **Impacts** Normal construction risks associated with a large-scale project include vehicle accidents, lifting accidents, accidents associated with the use of heavy equipment and slips, trips and falls.	Less construction risks due to simpler cover design.	Less construction risks due to simpler cover design.	Same as pending action.
Mitigation Measures Use standard construction practices required under the Washington Industrial Safety and Health Act.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
LONG-TERM PUBLIC HEALTH **Impacts** Of all three pending actions, the closure cover design has the most significant impact on public health during the 10,000-year post-closure period. The US Ecology Proposed Cover design is predicted to result in an offsite dose of 18 mrem/year and an onsite intruder dose of 310 mrem/year from all pathways. These	The Site Soils Cover is predicted to result in a greater impact than the pending action with an offsite dose of 32 mrem/year and an onsite	The Thick Homogenous Cover is predicted to result in an offsite dose of 15 mrem/year and an onsite intruder dose of 440 mrem/year. These	The Enhanced Asphalt Cover results in the lowest dose and risk of all the conceptual cover designs. It is predicted to result in an offsite dose of 9 mrem/year and an onsite intruder dose of 93 mrem/year.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
doses equate to an additional lifetime risk of fatal cancer to the offsite individual of 4.4 x 10^{-4}. The risk to the onsite intruder is 9.7 x 10^{-3}. There are no long-term health risks predicted from past disposal of non-radioactive hazardous wastes. [Note: Dose and risk values are for the most sensitive individual and include a NARM volume of 36,700 ft^3/year.]	intruder dose of 950 mrem/year. These doses equate to an additional lifetime risk of fatal cancer to the offsite individual of 1.1 x 10^{-3}. The risk to the onsite intruder is 2.9 x 10^{-2}.	doses equate to an additional lifetime risk of fatal cancer to the offsite individual of 4.0 x 10^{-4}. The risk to the onsite intruder is 1.4 x 10^{-2}.	These doses equate to an additional lifetime risk of fatal cancer to the offsite individual of 2.3 x 10^{-4}. The risk to the onsite intruder is 3.2 x 10^{-3}. The Enhanced Bentonite Cover also performs better than the pending action. The Enhanced Synthetic Cover performs worse due to the uncertainty of the durability of the synthetic low-permeability barrier.
Mitigation Measures Select a Closure Cover Schedule that maximizes early isolation of the waste. Use enhanced institutional controls to deter onsite intruders. Use enhanced disposal practices for NARM waste including a dedicated trench and deeper burial. Immediately construct a low-permeability interim cover over all filled trenches. Conduct performance and reliability monitoring of early constructed covers. Use enhanced environmental monitoring to validate groundwater modeling assumptions and conclusions.	Enhanced institutional controls to deter onsite intruders. Enhanced disposal practices for NARM waste including a dedicated trench and deeper burial. Immediately construct a low-permeability interim cover over all filled trenches.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts Meets regulatory requirements but results in additional risk of fatal cancer for the individual.	Offsite dose exceeds 25 mrem/year and onsite intruder dose exceeds 500	Same as pending action.	Same as pending action.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
	mrem/year. Additional risk of fatal cancer for the individual.		
EARTH **Impacts** Temporary site disturbance during construction resulting in higher potential for wind erosion and surface soil disturbance. **Mitigation Measures** Standard construction practices for erosion mitigation. **Significant Unavoidable Adverse Impacts** None identified	Same as pending action. Same as pending action. Same as pending action.	Same as pending action. Same as pending action. Same as pending action.	Same as pending action. Same as pending action. Same as pending action.
WATER **Impacts** Gross Beta activity is predicted to reach 180 pCi/L in groundwater during the 10,000-year post-closure period. This exceeds the 50 pCi/L Washington State Groundwater Quality Standard. **Mitigation Measures** Resample for radionuclides detected in groundwater to determine contributions from the commercial LLRW disposal site to gross beta. Expand annual environmental groundwater sampling	Gross Beta activity is predicted to reach 220 pCi/L in groundwater during the 10,000-year post-closure period. This increase is 42 pCi/L over the pending action. Resample for radionuclides detected in groundwater to determine contributions from the commercial LLRW disposal site to gross beta.	Gross Beta activity is predicted to reach 101 pCi/L in groundwater during the 10,000-year post-closure period. This increase is 79 pCi/L less than the pending action but still exceeds the Washington State Groundwater Quality Standard. Same as pending action.	Gross Beta activity is predicted to reach 101 pCi/L in groundwater during the 10,000-year post-closure period. This increase is 79 pCi/L less than the pending action. Same as pending action.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
to include beta-emitting nuclides detected in the US Ecology Site Investigation. Select a closure schedule alternative that provides early waste isolation. Immediately construct a low-permeability interim cover over al filled trenches. **Significant Unavoidable Adverse Impacts** Gross beta levels in groundwater exceed the current Ground Water Quality Standard during the10,000-year post-closure period.	Expand annual environmental groundwater sampling to include beta-emitting nuclides detected in the US Ecology Site Investigation. Same as pending action.	Same as pending action.	Same as pending action.
AIR Air quality issues from closure include fugitive dust generated from wind erosion of the cover. Some wind erosion potential until vegetation is established on the cover. [Long-term health impacts from air are discussed in this DEIS as a public health issue. See "Long-Term Public Health".] **Mitigation Measures** Plant cover with vegetation **Significant Unavoidable Adverse Impacts** None identified	Greater wind erosion potential than pending action due to less expected vegetation growth. Same as pending action. Same as pending action.	Same as pending action. Same as pending action. Same as pending action.	Same as pending action. Same as pending action. Same as pending action.
ECOLOGY **Impacts** No further impacts to the shrub-steppe habitat have been identified from site closure. Placement of a cover will encourage re-establishment of habitat and wildlife. Cover designs with silt loam soil, including the	Site Soils Cover will create a less desirable growing medium that may delay the return of the shrub-steppe	Same as pending action.	Same as pending action.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
Proposed US Ecology Cover, will be best for re-establishing flora and fauna.	habitat.		
Mitigation Measures Select a closure schedule alternative that includes early construction of the final cover. Plant final cover with native plants.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
CULTURAL RESOURCES			
Impacts Closing the commercial LLRW disposal site by leaving waste in place will impact tribal cultural values. Constructing a cover design that provides maximum waste isolation will help to mitigate the impact of cultural resources.	Site Soils Cover provides less waste isolation than pending action.	Thick Homogenous Cover provides less waste isolation than pending action.	Enhanced Asphalt and Enhanced Bentonite Covers provide greater waste isolation than the pending action. The Enhanced Synthetic Cover provides less waste isolation.
Mitigation Measures Protect undisturbed 15 acres in NW corner. Select a closure schedule alternative that provides early waste isolation. Use enhanced practices for NARM disposal including a dedicated trench and deeper burial of NARM waste. Plant cover with native species. Continue consultations with tribal governments. Continue consultation with the State Historic Preservation Office.	Same as pending action.	Same as pending action.	Same as pending action.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
Significant Unavoidable Adverse Impacts Impacts to tribal cultural resources.	Same as pending action.	Same as pending action.	Same as pending action.
LAND USE **Impacts** Site will not be suitable for general use within 100 years.	Same as pending action.	Same as pending action.	Same as pending action.
Mitigation Measures Enhanced Institutional Controls.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
CATASTROPHIC EVENTS **Impacts** Catastrophic events that could potentially affect the cover design are local ponding, earthquakes, and fire. Cover design characteristics that will be most reliable during catastrophic events include silt loam soil in upper 5 feet of cover and a flexible (self-healing) low-permeability barrier. The US Ecology Proposed Cover has both of these characteristics.	The Site Soils Cover has neither of these characteristics.	The Thick Homogenous Cover has silt loam but no low-permeability barrier. However, the thick homogenous soil layer in this cover may also be self-healing when subject to seismic activity.	All Enhanced Covers have silt loam but only the Enhanced Bentonite has a flexible highly reliable low-permeability cover.
Mitigation Measures None suggested	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
SOCIOECONOMIC **Impacts** No socioeconomic impacts associated with the selection of a cover design. Socioeconomic impacts from closing the site are discussed in Table 2.	Same as pending action.	Same as pending action.	Same as pending action.
CUMULATIVE EFFECTS **Impacts** Contributions to the cumulative effect from closure with the US Ecology Proposed Cover include all impacts listed under long-term health impacts, earth, water, air, ecology, cultural resources, land use and environmental justice. The significance of these contributions is expected to be small in comparison to contributions from elsewhere on Hanford.	Contributions from the Site Soils Cover are greater than from the pending action.	Contributions from the Thick Homogenous Cover are greater than from the pending action but less than the Site Soils Cover and the Enhanced Synthetic Cover.	Contributions from the Enhanced Asphalt and Enhanced Bentonite Covers are less than the pending action. Contributions from the Enhanced Synthetic Cover are greater than from the pending action.
Mitigation Measures All mitigation measures listed in this column.	All mitigation measures listed in this column.	All mitigation measures listed in this column.	All mitigation measures listed in this column.
Significant Unavoidable Adverse Impacts Whether significant unavoidable adverse impacts exist depends on future land use for the area and the total contribution from activities elsewhere at Hanford. Potential significant impacts are: Gross Beta groundwater concentration of 180 pCi/L. Onsite intruder dose of 310 mrem/year. Lifetime risk levels greater than 1 x 10^{-4}.	Gross Beta groundwater concentration of 220 pCi/L. Onsite intruder dose of 950 mrem/year. Lifetime risk levels greater than 1 x 10^{-4}.	Gross Beta groundwater concentration of 101 pCi/L. Onsite intruder dose of 440 mrem/year. Lifetime risk levels greater than 1 x 10^{-4}.	Gross Beta groundwater concentration of 101 pCi/L. Onsite intruder dose of 470 mrem/year for Enhanced Synthetic Cover. Lifetime risk levels greater than 1 x 10^{-4}

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
ENVIRONMENTAL JUSTICE **Impacts** Due to the hypothetical lifestyle scenario, the Native American community is predicted to be subject to a higher post-closure lifetime risk of cancer than the rural resident. The Native American living adjacent to the commercial LLRW disposal site has an additional .03% chance of fatal cancer compared to a non-native American. The Native American living on the commercial LLRW disposal site has an additional 0.5% chance of fatal cancer compared to a non-native American. **Mitigation Measures** All mitigation measures listed in this column although no mitigation measures are identified that would decrease the difference in impacts between the Native American and rural resident communities. **Significant Unavoidable Adverse Impacts** No adverse disparate impacts identified.	Higher overall risk than pending action but slightly less disparity. Same as pending action. Same as pending action.	Slightly higher overall risk but similar disparity. Same as pending action. Same as pending action.	Similar to pending action. Same as pending action. Same as pending action.
US ECOLOGY SITE INVESTIGATION **Impacts** The US Ecology Site Investigation may determine the need for a Resource Conservation and Recovery Act (RCRA) compliant cover. The US Ecology Proposed Cover does not meet the RCRA minimum technical requirements of a cover design although it may qualify for equivalency under RCRA. **Mitigation Measures** Add 12-inches more to Bentonite low-permeability barrier to make US Ecology Proposed Cover RCRA	Does not meet RCRA requirements. Defer placement of final cover and immediately	Same as pending action. Defer placement of final cover and immediately	Enhanced Asphalt and Enhanced Synthetic Covers meet minimum RCRA requirements. Enhanced Bentonite Cover may qualify for equivalency under RCRA.. No mitigation necessary for Enhanced Asphalt Cover or

SITE CLOSURE – CONCEPTUAL COVER DESIGN			
Pending Action – Proposed US Ecology Cover Design	**No Action Alternative-- Site Soils Cover**	**Alternative 1 – Thick Homogenous Cover**	**Alternative 2 –Enhanced Covers** • **Enhanced Asphalt** • **Enhanced Synthetic** • **Enhanced Bentonite**
compliant or defer placement of final cover and immediately cover site with interim low-permeability cover. **Significant Unavoidable Adverse Impacts** None identified	cover site with interim low-permeability cover. Same as pending action.	cover site with interim low-permeability cover. Same as pending action.	Synthetic Cover. For Enhanced Bentonite Cover, same mitigation as pending action. Same as pending action.
COSTS AND SURETY **Impacts** Assuming no construction of the cover before final closure, the estimated cost for the US Ecology Proposed Cover is $33,582,000 for closure in year 2056 and $22,937,000 for closure in year 2000. Surety is marginal for closure in year 2000. **Mitigation Measures** Research design and construction cost saving opportunities for US Ecology Proposed Cover. **Significant Unavoidable Adverse Impacts** None identified	Site Soils Cover was not evaluated for surety because construction of the Site Soils Cover is assumed to be an operational cost. N/A N/A	Estimated cost is $29,585,000 for closure in year 2056 and $20,207,000 for closure in year 2000. Surety is adequate for both closure dates. None suggested Same as pending action.	Enhanced Asphalt Cover is most expensive. Estimated cost is $55,650,000 for closure in year 2056 and $38,009,000 for closure in year 2000. Surety is only adequate for closure in year 2056. Surety for the Enhanced Synthetic and Enhanced Bentonite Covers is adequate for closure in year 2056 but marginal for closure in year 2000. Same as pending action. In addition, reinstate closure fund fee to adequately fund the Enhanced Asphalt Cover. Same as pending action.

Table 5: Site Closure – Closure Schedule: Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- "No Early Construction" Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
OPERATIONAL RISKS **Impacts** None	Same as pending action.	Same as pending action.	Same as pending action.
TRANSPORTATION RISKS **Impacts** None	Same as pending action.	Same as pending action.	Same as pending action.
COVER CONSTRUCTION RISKS **Impacts** Multiple construction periods may increase construction risks. The US Ecology Proposed Schedule has two major construction periods for the cover design.	The "No Early Construction" Schedule has one major construction period.	Same as pending action.	The Close-as-you-go Schedule has at least four major construction periods requiring the sections of cover to be joined as they are built. The extra labor involved may increase construction risks.
Mitigation Measures Use standard construction practices required under the Washington Industrial Safety and Health Act.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
LONG-TERM PUBLIC HEALTH **Impacts** Closure schedules that include early cover construction provide the earliest waste isolation and therefore the most protection for public health during the 10,000-year post-closure period. The US Ecology Proposed Cover immediately constructs a final cover over the first seven trenches including the chemical	No early cover construction means less waste isolation for the next 56 years. This may result in greater long-term public health risk.	Some early waste isolation but not as much as pending action.	More waste isolation than the pending action.

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- "No Early Construction" Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
trench leaving the rest of the trenches uncovered until final closure.			
Mitigation Measures Immediately construct a low-permeability interim cover over all filled trenches until they are covered with a final cover.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
EARTH			
Impacts Early cover construction over first seven trenches will mitigate soil disturbance impacts in those areas. The remainder of the disturbed soils will remain disturbed until final closure.	Greater areas of soil remain in disturbed state.	Less area of soil disturbance than the pending action.	Less area of soil disturbance than the pending action.
Mitigation Measures Selection of a cover with silt loam soil in upper five feet including US Ecology Proposed Cover, Thick Homogenous Cover, and Enhanced Covers. Immediate construction of a low-permeability interim cover over those trenches not affected by early construction. Plant early constructed covers with native plants.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
WATER			
Impacts Early cover construction over first seven trenches may reduce post-closure groundwater impacts.	Greater potential impact on groundwater quality due to	Greater potential impact on groundwater due to	Less potential impact on groundwater quality due to trenches

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- “No Early Construction” Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
	no early construction of cover.	less early construction.	being covered as filled.
Mitigation Measures Immediate construction of a low-permeability interim cover over those trenches not affected by early construction.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
AIR Early cover construction over first seven trenches may reduce radon emanation by providing an early radon barrier. The US Ecology Proposed Cover only covers seven trenches early, leaving the remainder of the filled trenches without a final cover until final closure.	No early radon barrier.	Less early radon barrier than pending action.	Greater early radon barrier than the pending action.
Mitigation Measures Immediate construction of a low-permeability interim cover over trenches not affected by early construction.	Same as pending action.	Same as pending action.	Same as pending actin.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
ECOLOGY **Impacts** Early construction of covers over first seven trenches may quicken the return of steppe-shrub habitat in that area.	No early establishment of shrub-steppe habitat.	Less early establishment of shrub-steppe habitat.	Greater establishment of shrub-steppe habitat.
Mitigation Measures Plant final cover with native plants.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- “No Early Construction” Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
CULTURAL RESOURCES **Impacts** Early construction of cover over first seven trenches will increase waste isolation and reduce impacts on tribal cultural resources.	No early construction means there are no reduction of impacts on tribal cultural resources.	Less reduction of impact on tribal cultural resources.	Greater reduction of impact on tribal cultural resources.
Mitigation Measures Selection of a cover with silt loam soil in upper 5 feet including US Ecology Proposed Cover, Thick Homogenous Cover, and Enhanced Covers. Immediate construction of a low-permeability interim cover over those trenches not affected by early construction. Plant early constructed covers with native plants. Continue consultations with tribal governments. Continue consultation with the State Historic Preservation Office.	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts Impacts to tribal cultural resources.	Same as pending action.	Same as pending action.	Same as pending action.
LAND USE **Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.
CATASTROPHIC EVENTS **Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- "No Early Construction" Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
SOCIOECONOMIC **Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.
CUMULATIVE EFFECTS **Impacts** Early cover construction may reduce impacts to public health, earth, water, air, ecology, and cultural resources. The reduction of these impacts are expected to be minor in comparison with total cumulative effects expected in comparison to contributions from elsewhere on Hanford.	Same as pending action.	Same as pending action.	Same as pending action.
Mitigation Measures None suggested	Same as pending action.	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.
ENVIRONMENTAL JUSTICE **Impacts** No impacts specifically associated with closure schedule.	Same as pending action.	Same as pending action.	Same as pending action.
US ECOLOGY SITE INVESTIGATION **Impacts** Early closure of 7 trenches may impede the location of new wells or sampling points in the Phase 3 US Ecology Site Investigation.	No early cover construction means there is no potential to impede the Phase 3 US Ecology Site Investigation.	Less impact than pending action.	Same as pending action.
Mitigation Measures Complete the Phase 3 US Ecology Site Investigation prior to cover construction, or	Same as pending action.	Same as pending action.	Same as pending action.

SITE CLOSURE – CLOSURE SCHEDULE			
Pending Action – Proposed US Ecology Closure Schedule	**No Action Alternative-- "No Early Construction" Schedule**	**Alternative 1 – Prototype Schedule**	**Alternative 2 – Close-as-you-go Schedule**
Design Phase 3 around the early construction of the cover, or Use an interim (versus final design) low-permeability cover for early construction that can be sampled through, modified, and removed and replaced if necessary to accommodate Phase 3 and any subsequent phases of a US Ecology Site Investigation. **Significant Unavoidable Adverse Impacts** None identified	Same as pending action.	Same as pending action.	Same as pending action.
COSTS AND SURETY **Impacts** Adequate surety for the US Proposed Schedule for all cover designs except the Enhanced Asphalt Cover.	Adequate surety for all cover designs.	Marginal surety for Enhanced Asphalt Cover. Adequate surety for all other cover designs.	Adequate surety only for the Thick Homogenous Cover. Marginal surety for the US Ecology Proposed Cover, Enhanced Synthetic Cover and Enhanced Bentonite Cover. Surety is inadequate for the Enhanced Asphalt Cover.
Mitigation Measures Reinstate closure fund fee to generators as needed.	None suggested	Same as pending action.	Same as pending action.
Significant Unavoidable Adverse Impacts None identified	Same as pending action.	Same as pending action.	Same as pending action.

2.0 BACKGROUND

2.1 Site History

On September 10, 1964, Washington State and U.S. DOE entered into a 100-year lease agreement for 1,000 acres of land at Hanford.[8] In 1965, the Atomic Energy Commission (AEC) licensed California Nuclear, Inc. to operate the commercial LLRW disposal site to allow for the disposal of low-level radioactive waste from non-defense activities. The commercial LLRW disposal site has been and continues to be licensed to receive only low-level radioactive waste and NARM. However, before 1985 the site disposed of material that was later defined as hazardous under the federal Resource Conservation and Recovery Act (RCRA). Since 1985, only waste characterized as low-level radioactive waste or NARM has been disposed at the site.

On December 31, 1966, WDOH assumed most of the licensing responsibilities through an agreement with the AEC. By 1979, the commercial LLRW disposal site was receiving approximately half of the nation's low-level radioactive waste volume. On October 4, 1979, transportation and shipping problems caused Governor Dixie Lee Ray to close the commercial LLRW disposal site. On November 19, the commercial LLRW disposal site reopened with more stringent transportation and shipping requirements. Since that time, compliance with transportation requirements by site users has significantly improved.

As a result of the imbalance between the small volumes of waste it was generating and the large volumes of waste it was receiving, Washington State sought passage of the Low-Level Radioactive Waste Policy Act of 1980 (Act), P. L. 96-573. The Act made each state responsible for disposal of its own low-level radioactive waste and encouraged the formation of compacts between states to manage low-level radioactive waste on a regional basis. The Act gave compacts the power to exclude low-level radioactive waste, generated outside the compact, from their regional facility. This "exclusionary" authority was an important incentive for states to join the compact system.

Before Washington State could comply with the Act, the citizens of Washington approved Initiative 383 on November 4, 1980. Initiative 383 banned the disposal of all non-medical waste generated outside Washington State. In 1981, U.S. District Court found Initiative 383 unconstitutional. Washington State then moved forward with forming a low-level radioactive waste compact with other states.

In 1981, the states of Washington, Alaska, Hawaii, Idaho, Montana, Oregon, and Utah formed the Northwest Interstate Compact. Wyoming exercised its option to join the Northwest Compact in 1992. Congress ratified the Northwest Compact in 1985 and

[8] In 1993, U.S. DOE exercised its option under the lease and asked the state to return 900 of the 1,000 acres, leaving 100 acres of land for the commercial LLRW disposal site.

passed the Low-Level Radioactive Waste Policy Amendments Act (Amendments Act) of 1985, P.L. 99-240. The Amendments Act allowed state compacts with operating sites to exclude low-level radioactive wastes beginning in 1993. In 1993, the Northwest Compact exercised its authority to exclude low-level radioactive wastes generated outside its member states. By formal agreement between the Northwest Compact and the Rocky Mountain Compact, waste generated in the states of Nevada, Colorado, and New Mexico have been provided limited use of the commercial LLRW disposal site since 1992.

2.2 Regulatory, Legal, and Policy Considerations

Several state and federal agencies have a role in regulating the commercial LLRW disposal site. Operations and closure of the commercial LLRW disposal site are regulated by WDOH under the authority of the Washington Nuclear Energy and Radiation Control Act, Chapter 70.98 RCW, and through agreement with the U.S. Nuclear Regulatory Commission (U.S.NRC). Other state and federal agencies include the Department of Ecology, the Washington Utilities and Transportation Commission (WUTC), the U.S. Environmental Protection Agency (U.S. EPA), the U.S. Department of Transportation (U.S. DOT) and the U.S. DOE as the site landlord. The primary instrument for regulating the commercial LLRW disposal site is the Washington State Radioactive Materials License, WN-I019-2, issued by WDOH to US Ecology.

In addition to the WDOH regulatory requirements for operation and closure, the commercial LLRW disposal site is also subject to federal RCRA corrective action requirements. These requirements address cleanup of non-radioactive hazardous substances and are implemented through the Hanford state dangerous waste treatment, storage, and disposal permit (number WA7 89000 8967). This permit is issued to US DOE and is applicable to the entire Hanford Site, including the commercial LLRW disposal site. The Department of Ecology recently proposed revisions to the Hanford permit that would require USDOE to fulfill corrective action requirements at the commercial LLRW disposal site, if necessary. The proposed revisions also allow for the corrective action requirements to be temporarily deferred pending a full evaluation of the results of a recent US Ecology Site Investigation and/or remediation of the commercial LLRW disposal site. The Department of Ecology proposed permit conditions are currently on appeal to the Washington Pollution Control Hearings Board.

Contamination at the commercial LLRW disposal site is also subject to cleanup requirements in accordance with the Model Toxics Control Act (MTCA), Chapter 173-340 WAC. Based on current information, the Department of Ecology has used its discretion within MTCA to recognize WDOH as the overall lead agency at the commercial LLRW disposal site under Chapter 246-250 WAC and has not invoked cleanup under MTCA. The Department of Ecology reserves the right under MTCA to take future remedial action if necessary.

2.2.1 Applicable Requirements

There are three types of applicable requirements included in this DEIS. They are mandatory requirements, guidance values, and consideration values. Mandatory requirements are those requirements that must be met. Guidance values are limits that have not been defined by regulation but have been established to "guide" a regulatory agency on how it regulates a facility or activity. Consideration values are regulatory or guidance values that are not *directly* applicable to the commercial LLRW disposal site but are considered in this DEIS. The agencies have discretion on how a guidance or consideration value is applied. Decisions to not apply a guidance value are generally made when another, more appropriate standard, is available. Consideration values are often used for informational purposes only. Table 6 lists the regulations, laws and other citations that are referenced in this DEIS.

Regulatory standards generally represent the maximum allowable limit for a radionuclide or hazardous constituent. These maximum allowable limits are usually acceptable only if it is not reasonable to achieve a lower limit. The concept of achieving a lower limit is central to many regulatory standards and is critical for ensuring maximum protection of public health and the environment. In the field of radiation regulation, this concept is known as ALARA and means "as low as reasonably achievable." ALARA mandates that every reasonable effort must be made to limit exposure to radiation to the extent practicable taking into account current technology, public health, worker safety, costs, and other socioeconomic considerations.

Table 6: Key Requirements for Evaluation of License Renewal, NARM Acceptance, and Site Closure for the Commercial LLRW Disposal Site DEIS

CITATION OR NAME	DESCRIPTION OF REQUIREMENT	APPLICABILITY: M = Mandatory G = Guidance CV = Consideration Value		
		L*	N*	C*
WDOH, Chapter 246-250 WAC, Radioactive Waste – Licensing Land Disposal	Limits effluents that migrate offsite (groundwater, surface water, air, soil, plants, or animals) to no more than 25/75/25 mrem/year to any member of the public. Requires an approved closure plan that covers each disposal unit as it is filled with waste.	M	M	M
U. S. NRC, 10 CFR Part 61 DEIS	Establishes a 500-mrem/year onsite inadvertent intruder guidance level.	G	G	G
WDOH, Chapter 246-249 WAC, Radioactive Waste – Use of the Commercial LLRW Disposal Site	Establishes a volume limit for acceptance of diffuse NARM. The current level of 8,600 cubic feet per year is stayed by a court order that allows 100,000 cubic feet per year with a “rollover provision.”	M	M	--
WDOH, Chapter 246-221 WAC, Radiation Protection Standard	Establishes following limits: Occupational dose limit of 5,000 mrem/year for adults and 500 mrem/year for minors and pregnant women. 500 mrem/year to public from effluents and external radiation[9] 100 mrem/year to public from all licensed operations[10]	M	M	--
WDOH, Chapter 246-247 WAC, Radiation Protection – Air Emissions (references National Emissions Standard for Hazardous Air Pollutants 40 CFR Part 61)	Air concentrations to general public shall not exceed 10 mrem/year.	M	M	M
Washington Industrial Safety and Health Act (WISHA) Chapter 49.17 RCW	Establishes safe and prudent practices for the industrial workplace.	M	M	M

[9] The US Ecology license requirement is 400 mrem/year.
[10] This requirement does not include the dose from U.S. DOE facilities.

CITATION OR NAME	DESCRIPTION OF REQUIREMENT	APPLICABILITY: M = Mandatory G = Guidance CV = Consideration Value		
		L*	N*	C*
Washington Department of Health (WDOH), Chapter 480-92 WAC	Empowers the Washington Utilities and Transportation Commission to establish the rate and fee structure for the commercial LLRW disposal site.	M	M	--
Washington Department of Ecology, Chapter 43.200 RCW, Radioactive Waste Act	Restricts low-level radioactive waste disposal at the commercial LLRW disposal site to the Northwest and Rocky Mountain Compacts.	M	--	--
Washington Department of Ecology, Chapter 173-200 WAC, Groundwater Quality Standards	Establishes numerical standards for groundwater quality for the protection of both public health and the environment.	M	M	M
WDOH Public Water Supplies, Chapter 246-290 WAC (Incorporates 40 CFR Part 141 Safe Drinking Water Act Requirements)	Establishes standards for the quality of public drinking water supplies including a 4-mrem/year dose.			M
Court Order based on Agreement between US Ecology and WDOH	Establishes interim acceptance of NARM volumes of 100,000 ft^3/year and requires rulemaking to adopt an appropriate limit.	--	M	--
Washington Department of Ecology, Dangerous Waste Rules, Chapter 173-303-WAC (references Federal RCRA Corrective Action Requirements)	Regulates corrective actions for releases of past disposal of hazardous or mixed wastes using cleanup levels established in the Model Toxics Control Act Regulations.	--	--	CV
U.S. Department of Energy (DOE), DOE Order 5400.5	Limits the dose to 100 mrem/year to general public for all U.S. DOE operations.[11]	CV	CV	CV
U.S. Department of Transportation, Title 49 Code of Federal Regulations	Regulates transport of low-level radioactive waste.	M	M	--

[11] Although the commercial LLRW disposal site is not operated or regulated by U.S. DOE, it is located on U.S. DOE land.

CITATION OR NAME	DESCRIPTION OF REQUIREMENT	APPLICABILITY: M = Mandatory G = Guidance CV = Consideration Value		
		L*	N*	C*
WDOH, Hanford Guidance for Radiological Cleanup	Establishes a cleanup level of 15 mrem/year for Hanford for 1,000 years post-cleanup. Discretionary applicability for WDOH-licensed sites.	--	--	CV
WDOH, Radionuclide Cleanup Standards for Radioactive Material Licensed Sites, Chapter 246- 246 WAC	Establishes an offsite cleanup level of 25 mrem/year and an onsite cleanup level of 100/500 mrem/year for radioactive material license sites, excluding commercial LLRW disposal sites.			CV
Washington Department of Ecology, Chapter 173-340 WAC, Model Toxics Control Act (MTCA)	Establishes cleanup levels in the risk range of 1×10^{-6} to 1×10^{-5} for sites where a release or potential release of hazardous or radioactive constituents has occurred. Includes discretionary authority for sites where another, more appropriate standard, exists.	--	CV	CV
State Historic Preservation 36 CFR Part 61 Section 106	Requires consideration of archeological and cultural resources for federal projects or projects on federal land.	M	--	M

* L = Licensing N = NARM ACCEPTANCE C= Site Closure

2.2.2 Tribal Interests

The 1855 treaties between the federal government and the Yakama, Umatilla, and Nez Perce Nations ceded hundreds of square miles to the United States, while retaining the core reservation lands for tribal governments. Hanford, along with the commercial LLRW disposal site, lies entirely within this ceded territory. These treaties are active, valid, and upheld by courts and the Constitution of the United States, and may not be amended. These treaties reserve rights that support the continuity and well being of the tribal people and their cultural traditions. Tribal cultural traditions should be considered when making decisions about current and future activities at the commercial LLRW disposal site. U.S. DOE land use plans, described in Section 4.2.6, will affect how and when the tribes may use ceded lands within Hanford.

While Washington State is not party to the Treaties of 1855, it does have a “government to government” relationship with the tribes. This relationship is affirmed by the Centennial Accord of 1989 (State of Washington, 1989). WDOH and the Department of Ecology have coordinated and consulted with the tribes and presented their concerns, as they were understood, throughout this DEIS.

2.2.3 Washington State Policy on Importation of Radioactive Waste

Past and future state actions define the Washington State policy on the importation of radioactive waste. The policy is based on the equitable distribution and shared responsibility for the burden of low-level radioactive waste disposal. The policy is founded on the Washington State's commitment to the protection of public health and compliance with all laws and regulations.

Washington State supports the Low-Level Radioactive Waste Policy Act of 1980 and the Policy Amendments Act of 1985, described in Section 2.1. As Host State to the Northwest Compact and through agreement with the Rocky Mountain Compact, Washington State currently provides disposal capacity to 22% of the nation's states. By doing so, Washington State believes it is doing its fair share and resists importation of additional wastes as legally allowed. Some of the past actions that have formed the current policy on the importation of radioactive waste include:

- 1980 passage of Citizen Initiative 383, limiting the importation of low-level radioactive waste to only medical waste, and then subsequent repeal of that initiative by the United States Ninth Circuit Court of Appeals for violation of supremacy and commerce clauses
- Host state for the Northwest Interstate Compact
- Acceptance of waste from the Rocky Mountain Compact
- Approval of disposal of 11.e(2) byproduct material at the Dawn Mining Company millsite, to aid in remediation
- 1996 NARM Settlement Agreement between Washington State and US Ecology to limit NARM disposal based on public health concerns

Each of the above actions has been based on the equitable distribution of the burden of low-level radioactive waste disposal and the consideration of public health and compliance with laws and regulations. Equitable distribution, public health, and compliance with laws are expected to continue to influence future policy regarding the importation of radioactive wastes.

Figure 3: Commercial LLRW Disposal Site - Chronology of Significant Events

1965:
- Site licensed to California Nuclear, Inc. and begins accepting low-level radioactive waste

1968:
- Nuclear Engineering Company acquires California Nuclear, Inc. and takes over as site operator

1970:
- Chemical trench holding approximately 17,000 cubic feet of waste is closed

1979:
- Site closed in October due to transportation-related noncompliance events; reopened November

1980:
- LLRW Policy Act passed by Congress
- Packaging requirements become more stringent, cardboard packaging no longer accepted
- Initiative 383 approved banning disposal of all non-medical waste generated out of state

1981:
- U.S. District Court finds Initiative 383 unconstitutional
- Nuclear Engineering Company changes its name to US Ecology, Inc.

1983:
- U.S. NRC adopts 10 CFR Part 61 for regulating commercial LLRW low-level radioactive waste sites

1985:
- Hazardous scintillation fluids banned from disposal
- LLRW Amendments Act of 1985 passed

1986:
- SEPA checklist completed for License Renewal: Determination of Non-significance

1991:
- SEPA checklist completed for License Renewal: Determination of Non-significance

1993:
- Northwest Compact restricts disposal to member states and Rocky Mountain Compact states

1995:
- WDOH sets a NARM volume limit of 8,600 cubic feet per year
- US Ecology challenges volume limitations by filing a law suit

1996:
- A court order imposes 100,000 ft^3/year NARM volume limit, pending rulemaking
- US Ecology submits *Site Stabilization and Closure Plan* for approval
- SEPA Determination of Significance for License Renewal, NARM Acceptance, and Site Closure

1997:
- DEIS started
- US Ecology Site Investigation begins

1999:
- Trojan reactor vessel disposed at commercial LLRW disposal site

2.3 Waste Types and Volumes

Records are kept on both the activity and volume of waste disposed at the commercial LLRW disposal site. The total activity, referred to as the "source term," is measured in curies. The source term is important for predicting environmental consequences and long-term public health risk from the commercial LLRW disposal site. Over 600 different radionuclides have been disposed at the commercial LLRW disposal site (Blacklaw 1998). As of January 1, 2000, the site had received 13.5 million cubic feet of waste containing 3.9 million curies of radioactivity (Elsen 2000). Annual volumes of low-level radioactive waste disposed at the commercial LLRW site have ranged from a low of 15,000 ft^3/year in 1970 to a high of 1,440,000 ft^3/year in 1981. Figure 4 shows that waste volumes have generally decreased since their high in the early 1980's. This decrease is attributed to the direct effect of the low-level waste compact system and waste reduction due to the increased costs of disposal.

WDOH estimates that an average volume of less than 200,000 ft^3/year of low-level radioactive waste plus NARM will be disposed at the commercial LLRW disposal site[12] (Elsen 2000). Based on this estimate, the commercial LLRW disposal site is expected to receive 24.9 million cubic feet of waste by closure in year 2056 (Elsen 2000). Adjusting for decay, the commercial LLRW disposal site is expected to contain 350,000 curies of radioactivity 100 years after closure[13] (Thatcher and Elsen 1999).

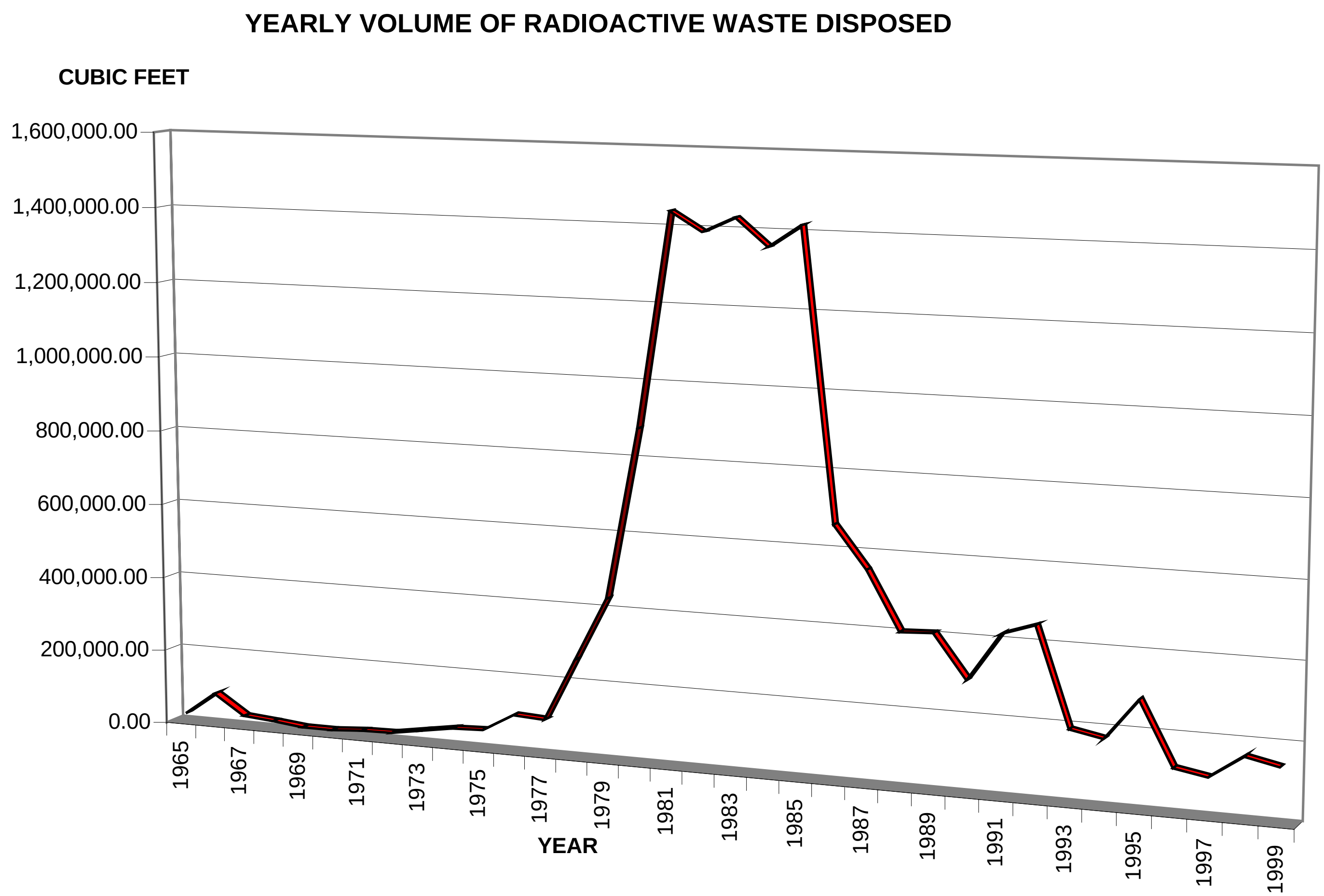
2.3.1 Low-Level Radioactive Waste

On December 27, 1983, WDOH adopted the U.S. NRC classification system for low-level radioactive waste.[14] There are three classes of low-level radioactive waste: Class A, B, and C. Class A waste contains the lowest concentration of radioactivity of the waste classes, and Class C contains the highest concentration. Class A waste is primarily trash such as discarded protective clothing and biomedical waste. Class A waste makes up over 98.0% by volume of the classified waste disposed at the commercial LLRW disposal site and poses the least potential threat of the low-level radioactive wastes. Class B waste comprises 0.83% by volume of the classified waste disposed at the site. Class B waste contains a higher proportion of materials with longer half-lives and includes industrial waste and wastes from nuclear power plants such as hardware, filters, and other equipment. Class C waste has the highest waste concentrations and accounts for 0.75% by volume of waste at the site. Class C waste is generated in nuclear power plants, medical research, and industrial activities. "Greater

[12] Predicted volumes are based on the average volumes from 1992 through 1999.
[13] This curie count was estimated for year 2172.
[14] Approximately 50% of all waste was disposed prior to 1984 and is unclassified.

than Class C” waste is any waste that exceeds the concentration limits for Class C. Waste classified as greater than Class C is not allowed at the site (Elsen 2000).

Figure 4: Annual Volume of Radioactive Waste Disposed



Although Class A waste comprises the majority by volume, it contributes the least to the activity count at the site. For classified wastes; i.e., waste disposed after 1984, Class A accounts for 2.6% of curies, Class B for 19.0%, and Class C for 78.3%.[15] Approximately 30% of all curies at the commercial LLRW disposal site are from unclassified wastes disposed prior to the establishment of the U.S. NRC low-level radioactive classification system in 1984. It is unknown what class these pre-1984 wastes would be according to today's standards.

2.3.2 Trojan Reactor

The Portland General Electric Trojan Reactor Vessel (TRV) was disposed at the commercial LLRW disposal site on August 9, 1999. It has 5 to 8 inch carbon steel walls and is completely sealed. The TRV has a volume of 8490 ft^3 and an associated activity of 1.54 million curies. The majority of these curies are expected to decay in a short period. For example, Co-60, Fe-55, and Mn-54, all radionuclides with half-lives from 1.5 to 5 years, represent 92% of the total activity within the reactor vessel. These radionuclides will all be decayed away in 50 years or less. In 100 years, the total reactor vessel activity will be less than 4% of the original activity.

The TRV was disposed of intact with its internal components encased in cement grout. The components were classified as Class C waste, pursuant to the U.S. NRC's radionuclide concentration averaging guidelines (Fordham 1998).

2.3.3 NARM Waste

The commercial LLRW disposal site accepts NARM waste from throughout the country. NARM is not subject to the Low-Level Radioactive Waste Policy Act of 1980 and therefore is not restricted by the exclusionary provisions of the Act. *Diffuse* NARM includes such wastes as pipe scale from routine maintenance on oil and gas pipelines, soils from the cleanup of mineral processing sites, and laboratory trash from the production of accelerator produced pharmaceuticals. Almost all *discrete* NARM comes from measuring devices, gauges, and radium needles used in medical procedures.

Until 1992, NARM volumes were recorded as low-level radioactive waste. Beginning in 1992, NARM volumes at the commercial LLRW disposal site were counted separately from low-level radioactive waste. Based on the past eight years of records, NARM volumes disposed at the commercial LLRW disposal site have ranged from a high of 77,000 ft^3/year to a low of 11,600 ft^3/year. Overall, NARM volumes have averaged less than 30,000 ft^3/year and this average annual volume is expected to continue through closure.

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[15] The 78.3% figure includes Class C waste from the Trojan Reactor.

NARM accounts for 1.74% of the volume and less than .01% of the activity (approximately 188 curies) disposed at the site[16] (Elsen 2000). Based on past disposal records, an average of 35.7 curies of discrete and diffuse NARM waste are expected to be disposed annually in the commercial LLRW disposal site through year 2056. Adjusting for decay, this will equal 283 curies of NARM in the commercial LLRW disposal site 100 years after final closure[17] (Thatcher 2000).

Figure 5: Volume of Radioactive Wastes Disposed at the Commercial LLRW Disposal Site

Footnote Reference **18**&**19**

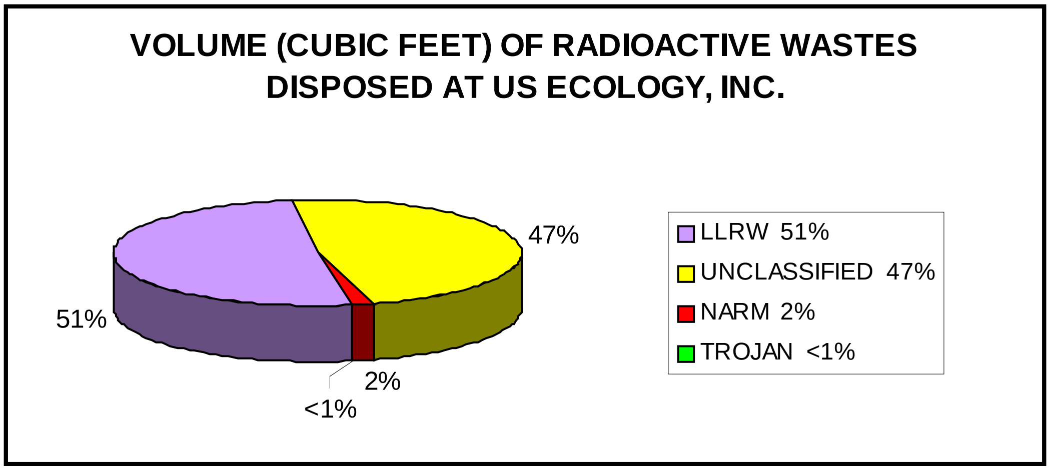
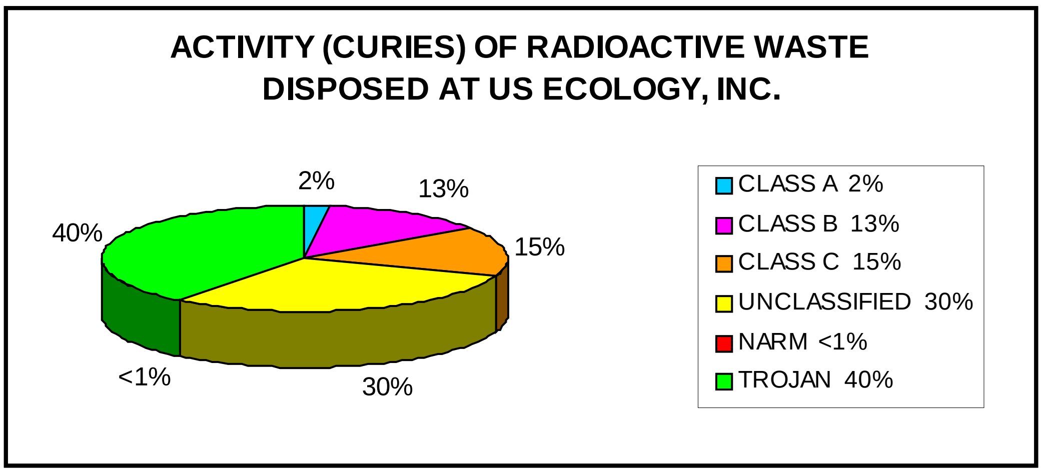


Figure 6: Activity of Radioactive Waste Disposed at the Commercial LLRW Disposal Site



[16] Volume and activities for NARM waste does not include NARM dispose prior to 1992.
[17] Prediction of NARM curies is based on an average volume of 36,700 ft^3/year of NARM through year 2056. Past average NARM volumes have actually been approximately 20% less.

2.3.4 Non-Radioactive Hazardous Waste

Historically, an estimated 17,000 cubic feet of non-radioactive hazardous wastes were disposed at the commercial LLRW disposal site between November 1965 and June 1970. These wastes were placed in the Chemical Trench located in the north-central portion of the site. Documented sources of waste in the Chemical Trench include nine drums of beryllium/copper solid metal shavings, 56 drums of unknown waste, and several thousand drums of phenolic waste. Additional small amounts of hazardous waste, incidental to radioactive waste from research labs and hospitals, were disposed in Trenches 1-10 and 13, until they were no longer accepted for disposal on October 28, 1985 (US Ecology 1985).

2.4 Site Operator

US Ecology, a wholly owned subsidiary of American Ecology, Inc., has been the site operator since 1968 under a sublease agreement with Washington State.[20] American Ecology, Inc., originally incorporated in 1983, is headquartered in Boise, Idaho.[21] American Ecology, Inc. provides a variety of hazardous and low-level radioactive waste management services. In 1997, 39% of the company's revenues were from its hazardous waste services, and 61% were from its low-level radioactive waste services.

US Ecology has a long history of providing low-level radioactive waste services. They have three closed disposal facilities: Sheffield, Illinois; Maxey Flats, Kentucky; and Beatty, Nevada.[22] US Ecology is also currently involved in siting and licensing two other commercial LLRW disposal sites. Both of these sites, Ward Valley, California, and Butte, Nebraska are on hold, pending either state or federal action.

The WUTC regulates revenues from the site. In 1995, the WUTC specified an annual revenue requirement of more than $5.6 million for the period between 1996 and 2001. This operating margin assures viability of the site and a reasonable disposal fee, regardless of waste volumes. This approach allows US Ecology to remain capable of securing the necessary revenue to ensure safe operations of the commercial LLRW disposal site.

2.5 US Ecology Site Investigation

US Ecology, with technical assistance from the Department of Ecology and WDOH, conducted Phase 1 and Phase 2 of a site investigation at the commercial LLRW

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[18]Based on NARM volumes since 1992.
[19]Includes all radioactive wastes disposed before 1984.
[20] The sublease between Washington State and US Ecology expires on July 29, 2005.
[21] California Nuclear, Inc. (CNI) was the original site operator. In 1968, CNI sold its assets to Nuclear Engineering Company (NECO). In 1981, NECO changed its name to US Ecology, Inc.
[22] US Ecology currently operates hazardous waste disposal sites in Beatty, Nevada and Robstown, Texas.

disposal site in 1998 and 1999 (US Ecology 1998c). The purpose of the US Ecology Site Investigation was to determine if any release has occurred at the site that is subject to corrective action under RCRA.

The US Ecology Site Investigation included eight vadose zone borings under the Chemical Trench and Trench 5. The borings were located at a distance from the trench edges to minimize the risk of drilling into waste materials. Trench 5 was selected because it is reported to contain high volumes of tritium-containing waste and volatile organic compounds, such as toluene, xylene and benzene. These compounds were residues of scintillation fluids on test tubes used in research. The Chemical Trench was selected for evaluation because it may contain unique chemical contaminants when compared with the other trenches. Two borings were completed at each location.

In addition to the borings described above, two rounds of ground water samples were collected from six existing onsite wells and one offsite well. The two sampling events occurred between September/October and December 1998. Table 7 provides further information regarding the sampling design of the investigation.

Non-radioactive Hazardous Constituents

Results of the US Ecology Site Investigation indicate the presence of non-radioactive hazardous constituents in the vadose zone and in the vadose zone gases below the Chemical Trench and Trench 5. Data indicate metals in the vadose zone including arsenic, beryllium, cadmium, and chromium. Semivolatile organic chemicals detected include acetone, 1,2,4-trimethyl-benzene, tetrachloroethane (PCE), toluene, and (total) xylene, but none exceeded screening levels[23]. Many volatile organic compounds were detected in vadose zone gas samples (US Ecology 1998d). There were no non-radioactive hazardous constituents detected in the groundwater samples.

<u>Conclusions</u>

The detection of metals at elevated concentrations and organic chemicals beneath the trenches in the vadose zone indicates a release and a continual threat of release of non-radioactive hazardous substances to the environment from the commercial LLRW disposal site (Ecology 2000). The results of the US Ecology Site Investigation indicate no public health risk from the concentrations detected in the vadose zone and a possible future risk from concentrations in the vadose zone gas (Ecology 2000). The possible risk from vadose zone gas is based on a prediction of how those concentrations may impact groundwater in the future. Using Henry Law's Constant, the Department of Ecology predicted that the existing concentrations of acetone, chloroform, and tetrachloroethene in the vadose zone gas may result in future groundwater concentrations that exceed MTCA cleanup levels at some point in the future (Ecology 2000). A Phase 3 US Ecology Site Investigation will be conducted to further characterize the commercial LLRW disposal site for the presence of non-radioactive hazardous contaminants (Ecology 2000).

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[23] Project screening levels were established at method detection limits for each constituent.

Radioactive Constituents

Results from the radiochemical analysis of the groundwater, vadose zone, and vadose zone gas indicate the presence of radionuclides in each media (WDOH 2000). The wells sampled are part of an environmental monitoring network and have a long history of analysis with which to compare results.

<u>Groundwater Samples</u>

In groundwater, gross alpha, gross beta, cobalt 60, tritium, technetium 99, and plutonium 239/240 were found above the detection limits. Technetium 99 (Tc-99), a beta emitter, was detected in all samples. The presence of Tc-99 is not surprising because the wells surrounding the commercial LLRW disposal site contain Tc-99 at low concentrations. The source of the Tc-99, a highly mobile radionuclide, is at least partly from a plume under the U.S. DOE 200 West Area (PNNL 1998a). In February 2000, the Department of Health analyzed Tc-99 in three US Ecology well samples. All three wells contained Tc-99, but at levels below those reported in the US Ecology Site Investigation results. Tc-99 has not been a routine part of historic monitoring at the commercial LLRW disposal site.

Tritium results from the US Ecology Site Investigation were consistent with historic results. The results show the trend of the documented tritium plume moving from the U.S. DOE 200 West Area through the groundwater under the commercial LLRW disposal site (PNNL 1999). From these data, it is not possible to determine if the commercial LLRW disposal site is contributing to the tritium plume.

The positive Cobalt 60 and Plutonium 239/240 results are not consistent with historical data. Historically, no previous groundwater samples have detected Co-60. Plutonium - 239/240 was reported in one 1995 groundwater sample, and was not seen in any other sample.

<u>Vadose Zone Samples</u>

Aside from the presence of naturally occurring radionuclides, one or more vadose zone samples also contained Americium 241, Nickel 63, Plutonium 238, 239/240, Strontium 90, and Tc-99. Of these, Americium 241 and the plutonium results appear inconsistent. Americium 241 was found in only one sample and the presence of plutonium at depth is unlikely because plutonium forms oxides in the vadose zone and is not readily mobile.

Nickel 63 was found in most samples. It is an activation product and its source is likely from the waste from power plants. Nickel 63 is mobile in soil and its presence in the vadose zone samples is not surprising.

Low levels of Tc-99 were found in several samples. Tc-99 is a fission product released to the environment through the fuel cycle. It is relatively mobile in soil. The reported levels are similar to other samples collected on the U.S. DOE Hanford site that were analyzed by the department.

Vadose Zone Gas Samples
During Phase I of the US Ecology Site Investigation, vadose zone gas samples were analyzed for Carbon 14 (as carbon dioxide) and Krypton 85. Both radionuclides are highly mobile and the detection of these radionuclides in soil gas was not surprising.

Conclusions
The US Ecology Site Investigation results give a generalized picture of radionuclides below the commercial LLRW disposal site. No environmental standards were exceeded, and the data do not indicate a risk to public health (WDOH 2000). For groundwater, the results show a trend of decreasing radionuclide concentrations from the upgradient wells to the downgradient wells. This trend would indicate that all or part of the radionuclides in the groundwater can be attributed to sources elsewhere on the Hanford Site (WDOH, 2000).

Results from the US Ecology Site Investigation, however, were not completely consistent with historic results and suggest an inaccuracy in the US Ecology Site Investigation results. Based on quality assurance and quality control concerns, WDOH will resample both the groundwater and the vadose zone to better understand the radionuclides in these media (WDOH 2000).

Table 7: US Ecology 1998 Site Investigation Summary

Media	Sample Sites and Locations	Sample Method	Constituents Sampled
Vadose Zone	Boring A1 – north Boundary Chemical Trench Boring B1 – south Boundary Chemical Trench Boring C1 – east boundary Trench 5 Boring D1 – west boundary Trench 5	30-degree drilling angle; 10 ft. from bottom corner of trench to 70 ft. below bottom of trench	Volatile organic compounds; semi-volatile organic compounds, metals, anions, cyanide, nitrate/nitrite, sulfide, organic content, gross gamma, isotopic plutonium, thorium, uranium, cobalt 60, nickel 63, strontium 90, technetium 99, radium 226 and 228, and americium 241.
Vadose Zone Gas	8 well installations; 4 in soil boring wells, 4 ~ 10 ft. from geophysical wells	30-degree drilling angle; 10 ft. from bottom corner of trench to 25 and 45 ft. below bottom of trench	Volatile organic compounds, semi-volatile organic compounds, methane, gross alpha/beta activity
Groundwater	6 onsite wells, 1 offsite well	1 W Trench 15, 2 S Trench 14A, 1 E Trench 6, 1 E Trench 1,	Temperature, pH, conductivity, anions, total dissolved solids, nitrate, nitrite, sulfide, total organic

Media	Sample Sites and Locations	Sample Method	Constituents Sampled
		1 NE Chemical T., 1 E Trench 10; mean depth of wells 358 ft. below grade	content, volatile organic compounds, semi-volatile organic compounds, total metals, hexavalent chromium, total organic halides, cyanide, phenols, gross alpha/beta activity, isotopic plutonium uranium, tritium, carbon 4, iodine 129, and technetium-99

2.6 Comparison to Other Commercial LLRW Disposal Sites

Nationwide there are three operating commercial LLRW disposal sites. Table 8 provides a comparison of the three active sites in Richland, Washington; Barnwell, South Carolina; and Clive, Utah. Currently, there are no other approved commercial LLRW disposal sites scheduled to begin operations.

Table 8: Comparison of Active Commercial LLRW Disposal Sites

Site Location	Richland, Washington	Barnwell, South Carolina	Clive, Utah
Date of Origin	1965	1971	1988
Operator	US Ecology, Inc.	Chem-Nuclear Systems, LLC	Envirocare of Utah, Inc.
Site Ownership	Federal	State	Private
Size of Facility	100 Acres	235 Acres	540 Acres
Description of Site	Rainfall: 6 inches/year Average depth to groundwater: 315 ft	Rainfall: 36 inches/year Average depth to groundwater: 41 ft	Rainfall: 7 inches/year Average depth to groundwater: 25 ft
Disposal Method	Shallow land burial	Shallow land burial	Below and above grade bulk disposal
Geographical area of Waste Accepted	Low-level radioactive waste accepted only from Northwest and Rocky Mountain Compacts; NARM accepted from all states	Low-level radioactive waste accepted from all states except North Carolina. South Carolina will begin exercising exclusionary authority in year 2008	No Low-level radioactive waste accepted from the Northwest Compact; waste accepted from all states
Waste Accepted	Class A, B, and C and NARM	Class A, B, and C	Most types of Class A, NARM, uranium mill tailings, some mixed waste
Disposal Cost	Variable	Variable	Variable

3.0 DESCRIPTION OF PENDING ACTION AND ALTERNATIVES

The three pending actions at the commercial LLRW disposal site are:

1. Renewal of the US Ecology Washington State Radioactive Materials License to operate the commercial LLRW disposal site.

2. Amendment of Chapter 246-249 WAC establishing a 100,000 cubic foot per year limit for diffuse NARM disposed at the commercial LLRW disposal site.

3. Approval of the July 1996 *Site Stabilization and Closure Plan* submitted by US Ecology.

In addition to the three pending actions, several alternatives to each pending action have been included in this DEIS. Alternatives were selected for the following reasons:

1. SEPA requires the evaluation of a No Action Alternative for each pending action.[24]

2. SEPA requires the evaluation of "reasonable alternatives" for each pending action. A reasonable alternative is defined as one that affords greater protection of the environment.

3. Although not required by SEPA, WDOH and the Department of Ecology included some alternatives for the purpose of representing an upper or lower bound of possible impacts.

Table 9 summarizes the pending actions and alternatives. For evaluation, the third pending action, Site Closure, has been divided into two parts: approval of the US Ecology Proposed Cover, and approval of the US Ecology Proposed Closure Schedule. Although each pending action is a separate action, none of the pending actions can be thoroughly evaluated without making assumptions about the other two actions. These assumptions are included in each of the descriptions following Table 9.

[24] Since the commercial LLRW disposal site is already in existence, the No Action Alternatives in this DEIS are defined somewhat differently than in most DEIS's.

Table 9: Pending Actions and Alternatives

Pending Action	Alternatives
1. Renew the US Ecology Radioactive Materials License	**No Action Alternative**: Deny License Renewal **Alternative 1**: Renew US Ecology License with Enhancements
2. Adopt NARM Volume Limit of 100,000 ft^3/year	**No Action Alternative**: Adopt Limit of 8,600 ft^3/year **Alternative 1**: Adopt Limit of 36,700 ft^3/year
3a. Approve US Ecology Proposed Cover	**No Action Alternative**: Site Soils Cover **Alternative 1**: Thick Homogenous Cover **Alternative 2**: Enhanced Cover • Enhanced Asphalt Cover • Enhanced Synthetic Cover • Enhanced Bentonite Cover
3b. Approve US Ecology Proposed Closure Schedule	**No Action Alternative**: "No Early Construction" **Alternative 1**: Construct Prototype **Alternative 2**: Close-as-you-go Schedule

Filled Site Alternative

In addition to the alternatives listed in Table 9, a "Filled Site" Alternative is evaluated in this DEIS. This alternative is included to determine the upper bound impacts from increased waste disposal at the commercial LLRW disposal site. The Filled Site Alternative assumes the commercial LLRW disposal site is filled to disposal capacity by either staying operational until the year 2215, or by receiving higher volumes of waste between now and closure in year 2056.[25] This alternative assumes the site will be relicensed, acceptance of NARM volumes will be limited to 100,000 ft^3/year, and closure will occur according to the 1996 US Ecology Closure Plan. The Filled Site Alternative is included for informational purposes only and is not considered a viable alternative at this time. Because the Filled Site Alternative is not considered a viable alternative, it was not included quantitatively in every evaluation in this DEIS.

[25] At current waste volumes, only approximately 60% of the site will be filled in year 2056.

3.1 License Renewal

Pending Action: Renew License

The purpose of the pending action is to renew the US Ecology License for operation of the commercial LLRW disposal site. US Ecology must submit a relicensing application every five years. The last application was submitted in January 1997. If approved, the license will be renewed with license conditions that, at a minimum, will continue to protect public health and the environment at current levels. During the five-year license period, WDOH is authorized to make updates and revisions to the license as necessary. To evaluate the impacts of renewing the license, it was assumed the commercial LLRW disposal site is operated until the year 2056, NARM is disposed at an annual volume of 36,700 ft^3/year, and the site is closed using the Enhanced Bentonite Cover. Appendix I describes current operating practices that are now required in the current license.

No Action Alternative: Deny License Renewal[26]

The purpose of this alternative is to close the commercial LLRW disposal site in the year 2000. The impacts of denying the license were evaluated using two different cover designs; the Site Soils Cover, and the Enhanced Bentonite Cover. Closing the commercial LLRW disposal site in the year 2000 would require the Northwest and Rocky Mountain Compacts to either store their waste or dispose of a portion of it at the commercial LLRW disposal site in either Utah or South Carolina. At this time, Utah is not licensed to accept Class B or Class C waste and South Carolina has decided to close its doors to out-of-region generators in the year 2008.

Alternative 1: Renew License with Operational Enhancements

The purpose of this alternative is to relicense the commercial LLRW disposal site with additional operational enhancements designed to enhance waste isolation, worker safety, and public health beyond the current protections. For evaluation of the Enhanced License Renewal Alternative, it was assumed the site would operate until the year 2056, NARM is disposed at an annual volume of 36,700 ft^3/year, and the site is closed using the Enhanced Bentonite Cover.

This alternative includes 18 operational enhancements that were selected based on a qualitative analysis of practices at other existing disposal facilities, disposal practices considered for potential future facilities in other states, and public perspectives on low-level radioactive waste disposal (WDOH 1998a). If this alternative is selected, the specifics of each of the following enhanced practices will be negotiated with US Ecology

[26] For evaluation purposes, the No Action Alternative denies the US Ecology application for relicensing. Strictly speaking, if the state took no action, the license remains in "timely renewal" status indefinitely. Timely renewal status means the current license requirements remain in effect until the relicensing application is approved or denied.

for inclusion in their license. The benefits and impacts of this alternative were qualitatively, not quantitatively, evaluated for public health risks and environmental impacts. Table 10 lists the enhanced practices included in this alternative.

Table 10: Operational Enhancements for License Renewal

Objective	Current Commercial LLRW Disposal Site Practice	Recommended Enhanced Practice	Enhancement Benefits
Reduce future waste subsidence due to unstable waste	Class A segregated from Class B and C; Class A Unstable must be 10 ft away from stable waste	Dispose stable and unstable waste in separate trenches beginning with Trench 12	Greater waste isolation and stabilization
Reduce above-ground storage time of waste	Storage time six months	Limit storage time 90 days*	Reduced surface radiation and increased worker safety
Reduce specific void space in Class A waste	Class A Stable, B, and C must have <15% by volume Class A Unstable must be reduced to extent practicable	Include Class A Unstable in the <15% void requirement	Increased waste stability
Increase depth of Class B waste	No depth requirement for disposal of Class B waste. Class C waste must be disposed five meters below cover surface grade	Dispose both Class B and C waste at least five meters below cover surface grade	Increased waste isolation and reduced surface radiation
Reduce edge of trench dose	Current edge of trench dose must be <10 mrem/hr	Limit edge of trench dose to less than five mrem/hr*	Increased worker safety
Require more radionuclides listed on manifest	Current U.S. NRC and U.S. DOT provisions allow some radionuclides to not be listed on the manifest	Limit the use of U.S. NRC and U.S. DOT provisions for "delisting" radionuclides in certain larger activity shipments	Increased worker safety, increase source term accuracy
Improve electronic record retention at site	Limited capability at commercial LLRW disposal site	Improve procedures for data entry, QA of data by licensee and by WDOH.	Improved waste tracking
Eliminate disposal of absorbed liquids	Liquids may be solidified, stabilized or absorbed	Allow only solidified or stabilized liquid waste*	Greater waste isolation and stabilization
Backfill trenches more often to increase trench stability	Unburied depth not to exceed six feet or within one business day of waste emplacement	Backfill as packages are disposed	Greater waste isolation
Increase environmental monitoring	Onsite monitoring of air, soil, vegetation, groundwater, and vadose zone	Review and enhance onsite and offsite environmental monitoring where appropriate	Increased environmental protection through early detection
Increase point of origin inspections	Inspection required only for suspended generators	Expand point-of-origin inspections and procedures	Increased generator compliance
Require High Integrity Containers (HICs) for chelated	HIC's may be used to stabilize Class A, B, and C waste and ion exchange	Double-pack chelated waste in HIC and ECB	Greater worker protection and

Objective	Current Commercial LLRW Disposal Site Practice	Recommended Enhanced Practice	Enhancement Benefits
waste	media; engineered concrete barriers (ECB) required for chelated waste		waste isolation
Improve methods to track waste location	Location of Class B and C waste, ECB's, oils, and chelates must be identified within 50 feet horizontally and 10 feet in vertical plane	Track waste location with Geographical Positioning System (GPS) or improved surveying methods	Improved waste tracking and monitoring
Increase requirements for ion exchange resins	Class A unstable ion exchange resins limited to 1 uCi/cc (microcurie per cubic centimeter) with half-life of more than five years	Require solidification of all exchange resins	Greater waste isolation and stability
Increase waste characterization	Visual periodic and for-cause inspections	Use gamma spectroscopy to identify radionuclides and verify waste activity	Increased worker safety, increase knowledge of sources term
Improve stormwater management	Berms around trenches to divert surface runoff	Enhance current stormwater system where appropriate	Greater waste isolation and groundwater protection
Improve dust control	Dispersal of excavated materials by wind erosion limited to allowable dose limits listed in license	Increase use of soil fixative, vegetative cover, and other mitigation as needed	Reduction of fugitive dust
Minimize radon emanation from trenches	NARM and other low-level radioactive waste are disposed in same trench with a soil radon barrier	Use separate trench for NARM waste with enhanced low-permeability radon barrier	Reduce post-closure radon dose to onsite intruder

* Enhancements were adopted in February 17, 1999, License Amendment #25

3.2 NARM Acceptance

Pending Action: 100,000 ft^3/year

The purpose of this action is to amend Chapter 246-249 WAC to allow disposal of 100,000 ft^3/year of diffuse NARM at the commercial LLRW disposal site. Under the court ordered settlement agreement, as described in Section 1.2.2, the current NARM volume limit is 100,000 ft^3/year. The pending action would initiate a rule amendment to adopt the 100,000 ft^3/year limit, including a "rollover provision". The rollover provision allows NARM volumes from previous years to be "rolled over" to the current year if the previous year's 100,000 cubic foot volume was not met. There is no limit to the volume of NARM that can be rolled over. Recent trends in NARM disposal at the commercial LLRW disposal site indicate the average demand for NARM disposal capacity is approximately 30,000 ft^3/year.

No Action Alternative: 8,600 ft^3/year

The purpose of this alternative is to establish a NARM Acceptance limit of 8,600 ft^3/year. This volume is the current NARM Acceptance limit in Chapter 246-249 WAC. Although 8,600 ft^3/year is currently in regulation, this provision has been stayed by the court order requiring a NARM volume limit of 100,000 ft^3/year. No rollover provision is included in this alternative.

Alternative 1: 36,700 ft^3/year

This purpose of this alternative is to establish a NARM Acceptance limit that approximates the actual demand for NARM disposal capacity. The actual demand was calculated based on an average of NARM volumes received at the commercial LLRW disposal site for the four-year period from 1992 to 1995.[27] The 36,700 ft^3/year volume of NARM was used in the evaluation of impacts for License Renewal and Site Closure. There is no rollover provision in this alternative.

3.3 Site Closure

There are two aspects of closure evaluated in this DEIS. The first is the "closure cover design" and refers to the *conceptual* design of the final cover that will be placed over the commercial LLRW disposal site. The second is the "closure schedule" and refers to the schedule for constructing the cover. All closure alternatives assume a 100-year institutional control post-closure period. During that period, all institutional controls such as deed restrictions, access restrictions, and identifying monuments will be maintained and the cover will be repaired as needed.

3.3.1 Closure Cover Design

In addition to the US Ecology Proposed Cover, there are five alternative cover designs evaluated in this DEIS. The purpose of evaluating the different conceptual cover designs is to identify cover characteristics that provide the best waste isolation and long-term reliability. The cover design alternatives are not intended to be prescriptive in design, but rather representative of certain performance levels.[28] *Selection of a final cover design alternative does not mean the commercial LLRW disposal site must be closed with that exact cover design, but rather must meet or exceed the performance and reliability of the selected alternative.*

The key differences between the cover design alternatives are the type and amount of gravel in the surface layers, the percent and volume of silt loam soil in the top five feet,

[27] 1992 was the first year NARM volumes were recorded separate from low-level waste. If more recent NARM volumes are considered, the average NARM disposed for the period of 1992 to 1997 is approximately 29,000 ft^3/year.
[28] The prescriptive nature of the conceptual covers was necessary for modeling their respective performances.

and the presence and/or characteristics of the low-permeability barrier. Gravel in the surface layer can minimize erosion but may increase infiltration through the covers. Silt loam soil is included in the cover designs because of its high water holding capacity. A high water holding capacity reduces infiltration through encouraging evaporation and plant growth. Low-permeability barriers are included in several of the cover designs because these barriers reduce radon gas and provide a second level of defense against infiltration. Drawings of each of the cover design alternatives are presented at the end of this section.

Pending Action: US Ecology Proposed Cover

The purpose of this pending action is to approve the US Ecology Proposed Cover submitted to WDOH in the 1996 Closure Plan. The US Ecology Proposed Cover is a multi-layer cover that is 16 feet, 4 inches thick (see Figure 7). The key characteristics of the cover are a 4-inch surface layer with 50% gravel, a 36-inch silt loam layer, and a 12-inch bentonite clay (12%) low-permeability barrier. The US Ecology Proposed Cover was designed in coordination with WDOH and the Department of Ecology. This cover was evaluated previously by WDOH and was determined to meet state and federal requirements[29] (WDOH 1999). The US Ecology Proposed Cover was evaluated with an assumed closure date of year 2056.

No Action Alternative: Site Soils Cover

The Site Soils Cover Alternative is composed entirely of site soils and is 8 to 11 feet thick (see Figure 8). As designed, the Site Soils Cover is not expected to meet minimum regulatory requirements and is therefore not considered a viable alternative. The purpose of this alternative is to evaluate the upper bound of impacts on the environment and long-term public health. Because the Site Soils Cover is not considered a viable alternative, it was not included quantitatively in every evaluation in this DEIS. When evaluated, a closure date of the year 2000 was assumed.

Alternative 1: Thick Homogenous Cover

The Thick Homogenous Cover is 16 feet, 6 inches thick and has a near-surface 60-inch thick silt loam layer over a second layer of site soils (see Figure 9). The purpose of this alternative is to evaluate the performance of a thick homogenous cover without a low-permeability barrier. The Thick Homogenous Cover has several differences from the US Ecology Proposed Cover. These include a thicker silt loam layer (60 inches versus 36 inches) a higher percentage of silt in the silt loam layer (85% versus 75%), and the absence of a low-permeability barrier. This cover design is similar to the design selected by US Ecology to close the Beatty, Nevada low-level radioactive waste disposal site (US Ecology 1989). The Thick Homogenous Cover was evaluated with an assumed closure date of year 2056.

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[29] The previous evaluation of the US Ecology Proposed Cover was done to satisfy NRC requirements and was less comprehensive than the evaluation in this DEIS.

Alternative 2: Enhanced Cover

The purpose of the Enhanced Cover is to evaluate the performance of various low-permeability barriers in conjunction with a 60-inch upper silt loam layer. The Enhanced Cover is similar to the Thick Homogenous Cover except for the presence of a low-permeability barrier. Compared to the US Ecology Proposed Cover, the Enhanced Cover has two distinct differences. The first is a thicker surface layer (60 inches versus 36 inches) with a higher silt content (85% versus 75%). The second is the type of low-permeability barrier. There are three variations to the Enhanced Cover, each with a different low-permeability barrier (see Figures 10, 11, and 12). The three variations are:

- Enhanced Asphalt Cover – contains a 12-inch asphalt barrier
- Enhanced Synthetic Cover – contains a synthetic barrier
- Enhanced Bentonite Cover – contains a 12-inch bentonite barrier

The Enhanced Asphalt Cover and Enhanced Synthetic Cover were evaluated with an assumed closure date of the year 2056. The Enhanced Bentonite Cover was evaluated with an assumed closure date of both the year 2056 and the year 2000. The difference in impacts between closure with the Enhanced Bentonite Cover on these two closure dates was used to determine the impacts of renewing the license.

3.3.2 Closure Schedule

"Closure schedule" refers to the schedule for constructing a final cover. In addition to the US Ecology Proposed Schedule, there are three closure schedule alternatives. The closure schedule alternatives range from constructing the cover entirely in the year 2056, to constructing the cover in phases before final closure. *Note: Constructing the cover in the year 2000 is not included in the closure schedule alternatives. Constructing a cover in year 2000 would result if the license were denied, and is evaluated as part of the Deny License Renewal alternative.*

Pending Action: US Ecology Proposed Schedule

The US Ecology Closure Plan proposes to construct a final cover on trenches 1 through 6 and the Chemical Trench immediately and to cover the remainder of the site in year 2056. The US Ecology Proposed Schedule is designed to provide early waste isolation for the earliest trenches, including those trenches that received non-radioactive hazardous waste.

No Action Alternative: "No Early Construction" Schedule

The "No Early Construction" Alternative takes no action on constructing a cover before final closure. The purpose of this alternative is to evaluate the impacts of leaving the filled trenches "open" until closure. Current practice is to cover filled trenches up to grade with site soils. This means waste may be subject to higher infiltration rates for the entire operating period, resulting in possible greater future risk.

Alternative 1: Prototype Schedule

The Prototype Schedule Alternative immediately constructs a final cover over two or three selected trenches and covers the remainder of the site in the year 2056. The purpose of this alternative is to evaluate early construction of a cover primarily for testing and monitoring a cover design. Although this alternative would provide more early waste isolation than the “No Early Construction” alternative, it would provide significantly less than the US Ecology Proposed Schedule. The Prototype Schedule provides the benefit of long-term monitoring of a cover design without an early commitment to a specific design.

Alternative 2: Close-As-You-Go Schedule

The Close-as-you-go Schedule alternative closes the site in four phases. For purposes of evaluation, it is assumed that a final cover is constructed on 25% of the site immediately, 25% in approximately 2019, 25% in 2037, and the last 25% in year 2056. The purpose of this alternative is to evaluate the costs and benefits of constructing a cover as the site is filled. This alternative provides the earliest waste isolation but requires an early commitment to a specific cover design.

3.4 Alternatives Not Considered

Other alternatives were considered but not included in this DEIS. Reasons for not including other alternatives were based on an initial assessment of reasonableness, environmental impacts, and the defined scope of this DEIS.

<u>License Renewal</u>

License renewal alternatives requiring a disposal method other than shallow-land burial were considered, but not included in this DEIS. These include above-ground and below-ground vaults. Instead, alternative disposal methods were considered as potential mitigation measures if significant adverse impacts, caused by shallow-land burial, could not be avoided.

<u>NARM Acceptance</u>

NARM alternatives greater than 100,000 ft^3/year were considered, but not included in this DEIS. Past trends indicate future NARM volumes received at the disposal site will be significantly less than 100,000 ft^3/year. Based on past and predicted volumes, WDOH determined that a NARM alternative exceeding 100,000 ft^3/year was not reasonable.

Site Closure

Closure alternatives other than leaving the waste in place and closing the site with a cover were considered, but not included in this DEIS. The Department of Ecology may require additional remedial actions under other cleanup laws including MTCA and RCRA Corrective Action. At this time, the Department of Ecology has determined that additional remedial actions are not appropriate.

Figure 7: Proposed US Ecology Conceptual Cover Design

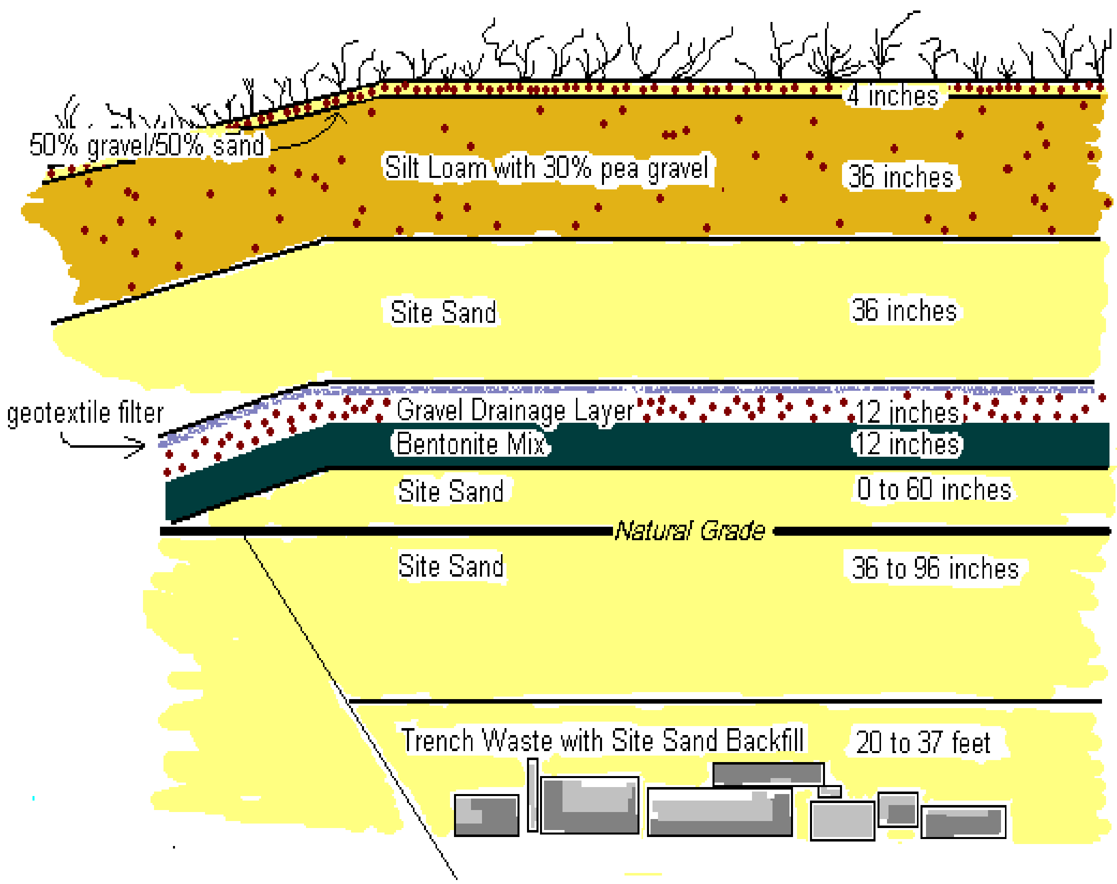


Figure 8: No Action Alternative – Conceptual Cover Design: Site Soils Cover

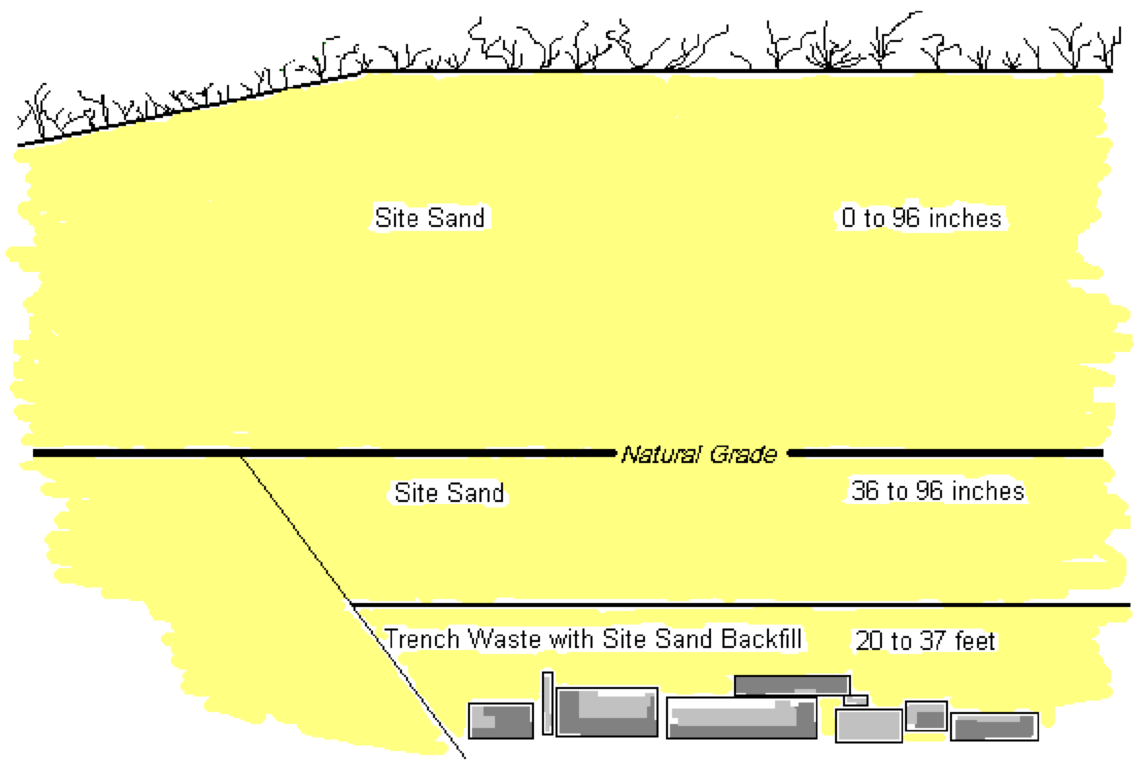


Figure 9: Alternative 1 – Conceptual Cover Design: Thick Homogenous Cover

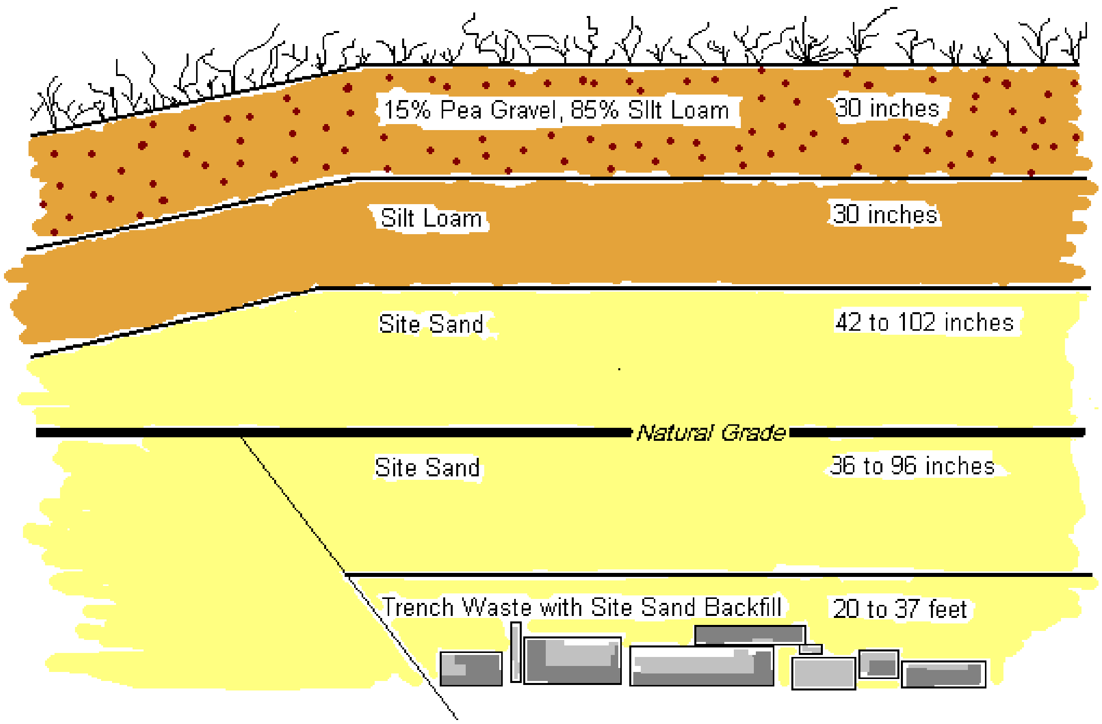


Figure 10: Alternative 2a – Conceptual Cover Design: Enhanced Asphalt Cover

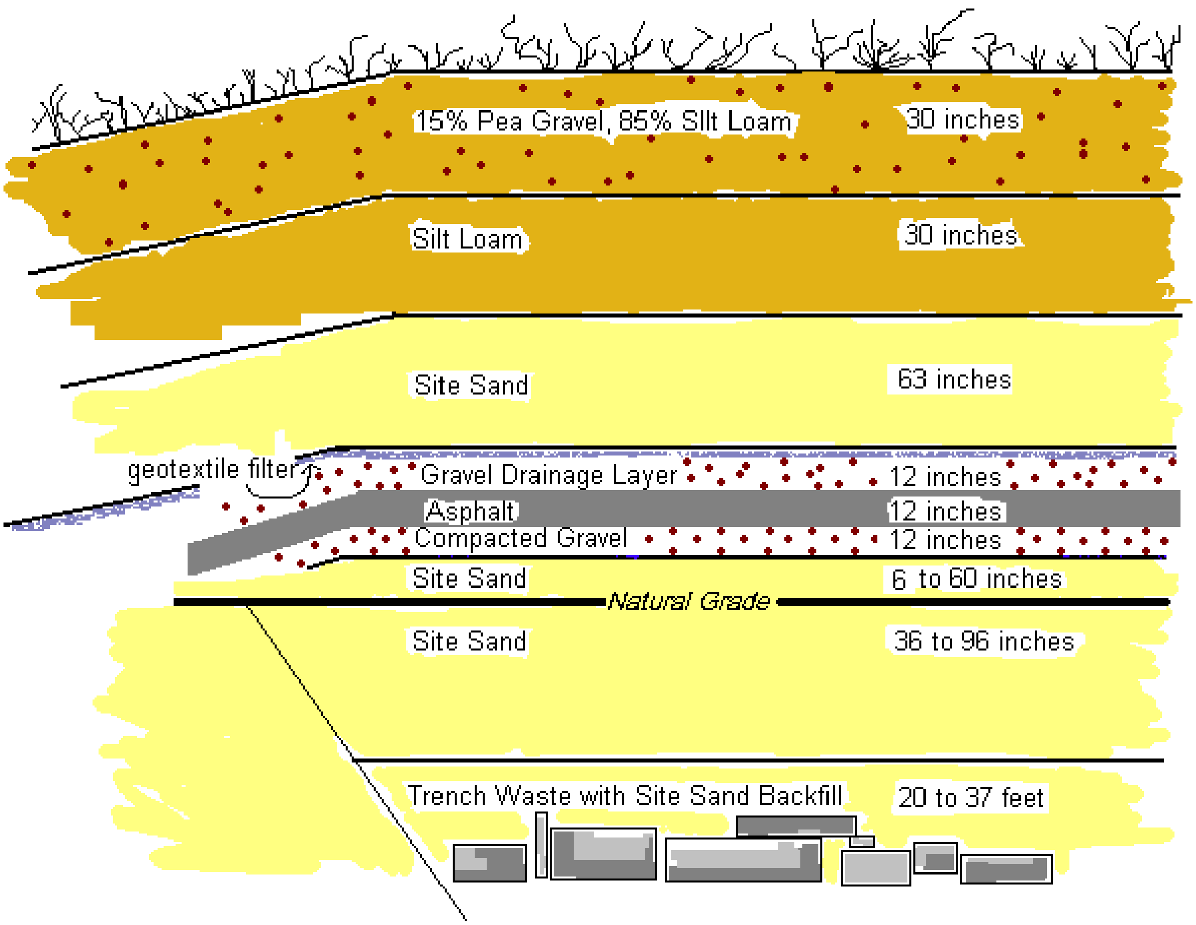


Figure 11: Alternative 2b – Conceptual Cover Design: Enhanced Synthetic Cover

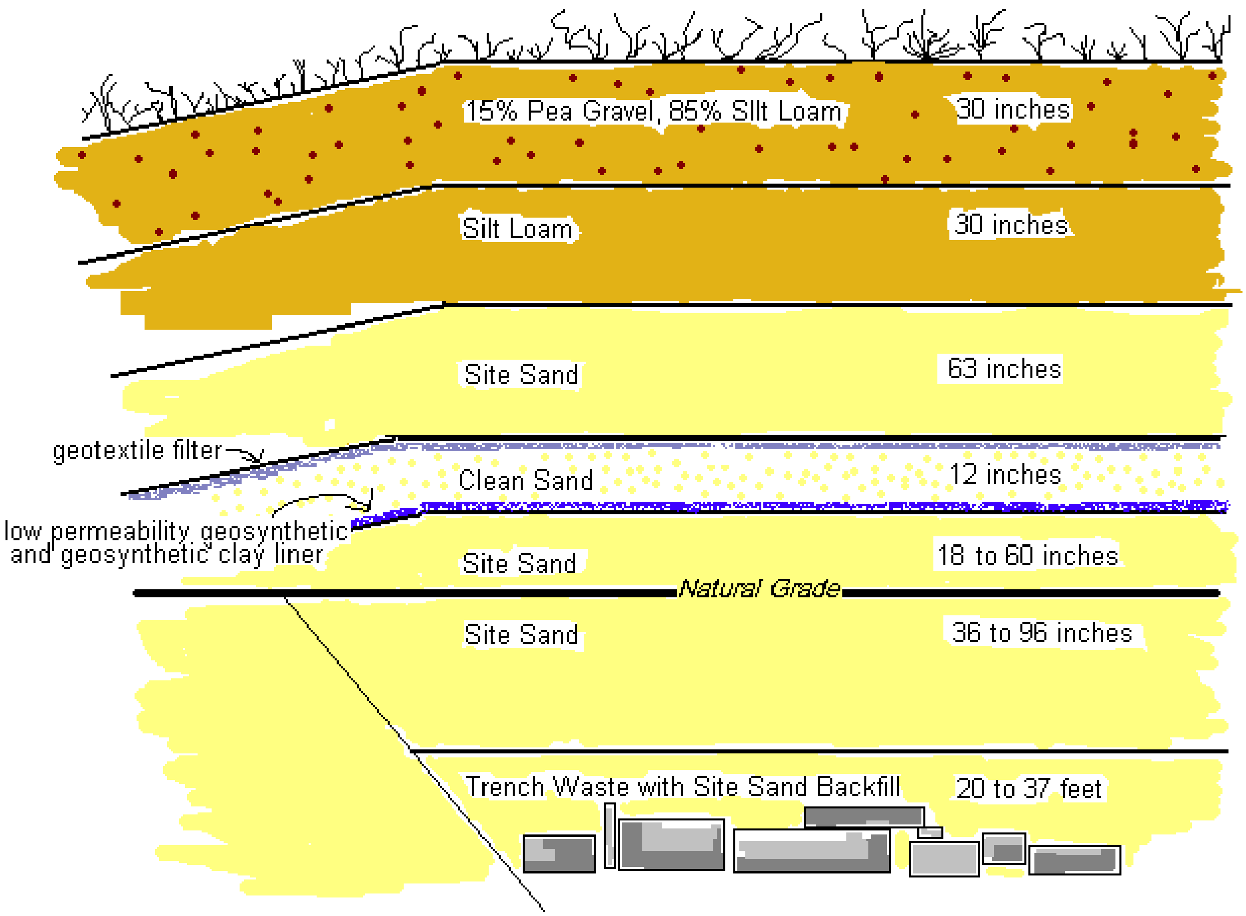
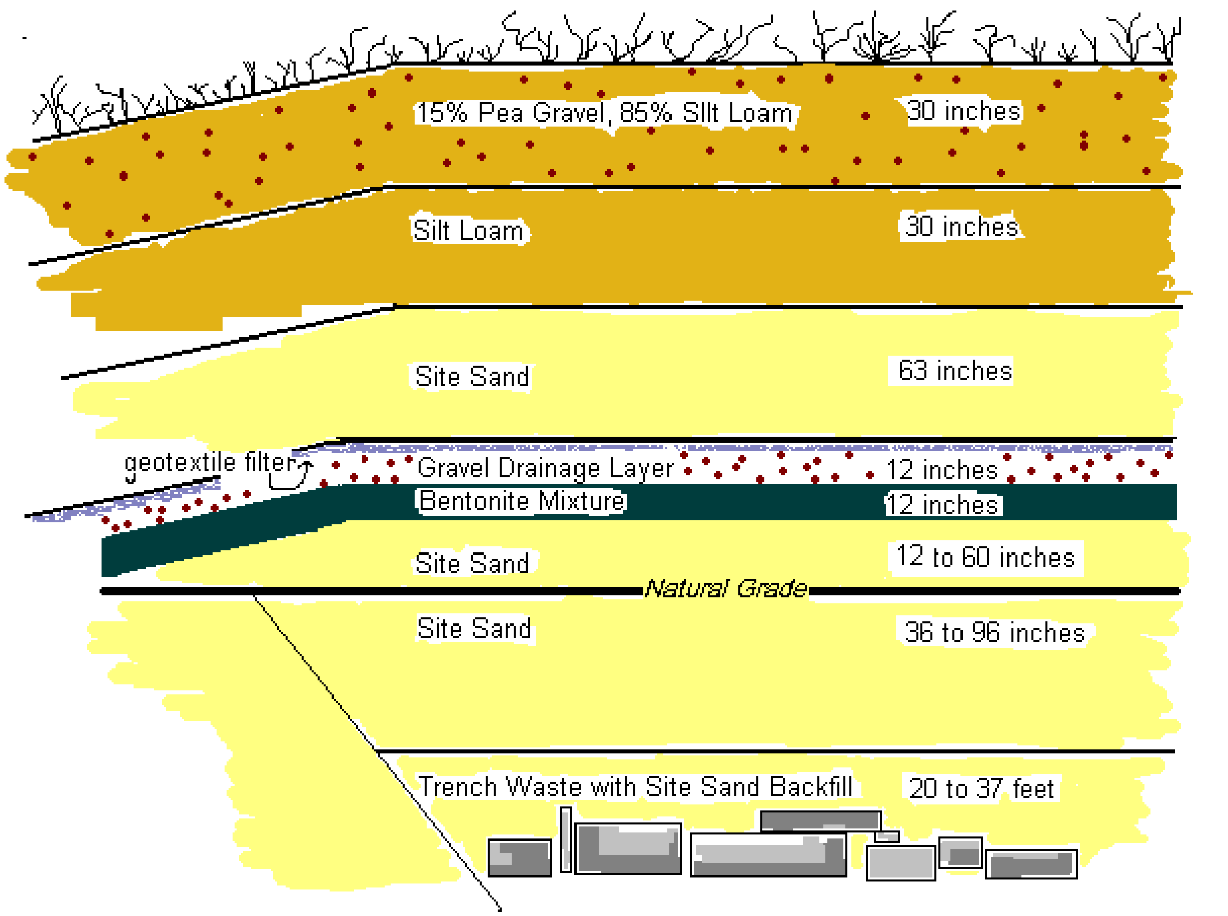


Figure 12: Alternative 2c– Conceptual Cover Design: Enhanced Bentonite Cover



4.0 PUBLIC HEALTH RISK, AFFECTED ENVIRONMENT, AND OTHER CONSIDERATIONS

This section discusses public health risks, environmental consequences, and other considerations for License Renewal, NARM Acceptance, and Site Closure. For each public health risk, environmental consequence or other consideration, the following is discussed:

- Applicable regulations, guidance values or "consideration values"
- Description of existing impacts
- Potential future impacts
- Summary of impacts, mitigation measures, and significant unavoidable adverse impacts.

4.1 Public Health Risk

Disposal of low-level radioactive waste presents a potential health risk to site workers and the public. This section evaluates both short-term and long-term health risks from License renewal, NARM Acceptance, and Site Closure. Short-term risks are those risks that occur before the site is closed and include risks associated with site operations, waste transportation, and construction of the cover at closure. Long-term risks are those health risks predicted to occur up to 10,000 years after the commercial LLRW disposal site is closed.[30] At this time, there are no known existing significant health risks to the public or site workers from the commercial LLRW disposal site (Fordham 2000) (Department of Ecology 2000).

4.1.1 Short-Term Public Health Risk

This section describes public health risks from site operation, waste transportation, and cover construction.

4.1.1.1 Operational Risks

Operational risks are risks to public health and worker safety associated with normal operations at the commercial LLRW disposal site. Applicable public health standards include:

- 25 mrem/year public dose from effluents migrating offsite (Chapter 246-250 WAC)

[30] Most risk assessments do not attempt to predict risk past 1,000 years, due to high uncertainty. Risks for the commercial LLRW disposal site have been predicted for 10,000 years because much of the risk does not occur until after 1,000 years.

- 100 to 500 mrem/year public dose from effluents and external radiation for licensed facilities (Chapter 246-221 WAC). The commercial LLRW disposal site is subject to 500 mrem/year based on occupancy factors and the original date of operation.

Applicable occupational standards:

- Occupational dose limits of 5,000 mrem/year (Chapter 246-221 WAC)
- Washington Industrial Safety and Health Act (WISHA) RCW 49.17

4.1.1.1.1 Operational Risks to Public Health

Chapter 246-250 WAC requires that effluents migrating off the commercial LLRW disposal site via groundwater, surface water, air, soil, plants, or animals contribute less than 25 mrem/year to any member of the public. This requirement is monitored and enforced through the current US Ecology License. At present, there is no significant dose to the public from effluents migrating off the commercial LLRW disposal site (Fordham 2000).

Chapter 246-221 WAC establishes an upper allowable limit of 500 mrem/year from all radiation sources at the commercial LLRW disposal site. The US Ecology License establishes a lower limit of 400 mrem/year for this requirement. Annual monitoring has consistently shown levels below 400 mrem/year (Fordham 2000).

4.1.1.1.2 Operational Risk to Worker Safety

Worker risk includes both non-radiological accidents and exposure to radionuclides. Non-radiological accidents are regulated by WISHA standards. Accidents that do occur at the commercial LLRW disposal site are often the result of normal occupational hazards such as slips, trips, falls, and lifting. Future accident rates can be estimated from past accident statistics. Occupational injuries and lost workdays for the recent ten-year period are shown in Table 11 (US Ecology 1998a).

Table 11: Commercial LLRW Disposal Site OSHA Incident Rates

Year	Incident Rate[31]	Lost Work Days	Number of Shipments	Cubic Feet of Waste Received
1997	4.76	0	208	102,671
1996	14.28	9	235	118,048
1995	4.34	1	583	282,401
1994	4.34	1	489	175,729
1993	8.69	2	446	192,108
1992	17.39	37	936	447,699
1991	12.00	47	979	419,207
1990	4.00	0	661	295,299
1989	0	0	810	408,291
1988	4.00	0	756	403,630

The rate of occupational accidents are considered within acceptable limits. Comparing incident rates with the number and volume of shipments received shows only minimal correlation between workload and accidents. This lack of correlation suggests that other variables, in addition to waste volume, are influencing the injury rate and lost workdays at the commercial LLRW disposal site.

4.1.1.1.3 Radiological Operational Risks

Workers are exposed to radioactivity through inspecting and handling the waste. Occupational dose limits for the commercial LLRW disposal site are 5000 mrem/year for general workers and 500 mrem/year for minors and pregnant women. US Ecology annually collects and analyzes data on dose limits. Employees wear thermoluminescent dosimeters (TLDs) to monitor external radiation to the whole body and extremities. Additionally, employees track daily exposures using self-reading dosimeters. Internal exposures are monitored by urinalysis for low and medium energy beta emitters and by direct counting of iodine in the thyroid gland. US Ecology compiles this information in its annual ALARA report (US Ecology 1998b). Table 12 presents a six-year record of the dose received by different categories of workers (Elsen 2000).

[31] Incident Rates (IR) were calculated by the following formula:

$$IR = \frac{N \times 200{,}000}{EH}$$

IR = Incident rate
N = Number of injuries and/or illness or lost work days
EH = Total hours worked by all employees during the reference year
200,000 = Base for 100 full-time equivalent workers (40 hours per week, 50 weeks per year)

Table 12: Average Occupational Doses Received at the Commercial LLRW Disposal Site mrem/year

Category	1994	1995	1996	1997	1998	1999
Site Worker	42	107	107	106	104	87
Radiation Control Technician	7	44	38	76	78	62
Management	5	3	0	10	0	4

All radiological doses were significantly below the occupational dose limits of 5,000/500 mrem/year. In the past, workers were most likely to receive their occupational dose from offloading waste packages upon arrival. In recent years, US Ecology has seen workers receive more of their occupational dose from waste handling activities required for the orderly placement of waste (US Ecology 1998a).

4.1.1.1.4 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

The commercial LLRW disposal site has historically operated with an acceptable accident and lost workday record. This record is expected to continue if the US Ecology License is renewed. The Enhanced Relicensing alternative contains several enhanced practices that are designed to increase worker safety. However, the Enhanced Relicensing alternative may also have the potential to increase worker dose by requiring more handling of the waste. All operational enhancements should be assessed for tradeoffs between environmental protection and worker safety.

Relicensing is not expected to cause the commercial LLRW disposal site to exceed the 25 mrem/year or 500 mrem/year dose limits established for the general public. This expectation is based on past monitoring results that show dose limits to be consistently below regulatory requirements.

Impacts of NARM Acceptance

NARM is not expected to have a significant impact on operational risks either through exposure to radiation or unacceptable accident rates. This expectation is based on the low activity of diffuse NARM waste and the historical safety record at the commercial LLRW disposal site.

Impacts of Site Closure

There are no additional operational risks from Site Closure.

Impacts of the Filled Site Alternative

Higher waste volumes associated with filling the site to capacity will increase the potential for non-radiological accidents at the commercial LLRW disposal site. There may also be an increased risk of radiological exposure from increased waste handling.

Mitigation Measures
Standard Washington industrial safety practices will be used during operations.

Significant Unavoidable Adverse Impacts
None identified.

4.1.1.2 Transportation Risk

This section evaluates both historic risks and future risks associated with the commercial LLRW disposal site. In 1999, 144,000 ft^3 of waste were shipped. This volume of waste was contained in 1,847 waste packages and was transported in 226 shipments. U.S. DOT regulates the transportation of radioactive waste through packaging, labeling, and record keeping requirements in Title 49 of the Code of Federal Regulations (CFR). In addition, WDOH includes specific transportation requirements in the US Ecology License for all waste shipped to the commercial LLRW disposal site.

4.1.1.2.1 Historic Transportation Risk

Historic transportation risk includes documented accidents, packaging failures, and non-compliance events that have occurred at the commercial LLRW disposal site. On October 4, 1979, the commercial LLRW disposal site was temporarily closed due to unsafe transport vehicles and improper waste packaging during transport. As a result, State Executive Order E079 was issued requiring additional efforts to reduce transportation incidents. These efforts include Washington State Patrol inspections of all vehicles carrying radioactive waste at ports of entry and the establishment of a permanent onsite WDOH state inspector at the commercial LLRW disposal facility. In 1992, WDOH also initiated a point-of-origin inspection program to further minimize packaging and transportation problems. This inspection program requires WDOH to conduct onsite inspections at generator facilities. In addition to transportation risk from improper packaging, there were two accidents in the 1980s involving trucks transporting radioactive waste to the commercial LLRW disposal site (Robertson 2000).

Although there have been no documented significant impacts to public health from any transportation incidents associated with the commercial LLRW disposal site, some of these incidents had the potential for such impacts. The increased inspections by the Washington State Patrol and WDOH have greatly reduced the number of shipping and packaging violations; however, WDOH recognizes that continued effort is required to eliminate such violations altogether.

4.1.1.2.2 Future Transportation Risk

Future transportation risk associated with the commercial LLRW disposal site was predicted using RADTRAN 4 (Weiner 1998). RADTRAN 4 is a model that predicts separate risks for individuals located along the transportation corridor, the crew riding in the transport vehicle, and occupants of other vehicles sharing the route. The dose and risk figures reported in this section only apply to the individuals located along the transportation corridor, as these are usually of the most interest to the public.

There are four routes used to transport waste to the commercial LLRW disposal site:

- **Albany route**, from Albany, Oregon, east along the Columbia Gorge to Umatilla, Oregon, and then north on I-82 to I-182, to State Route 240, to the commercial LLRW disposal site.

- **Spokane route**, from Coeur d'Alene, Idaho, west on I-90 to Ritzville, Washington, then south on US 395 to Pasco, Washington, then north on I-182, to State Route 240, to the commercial LLRW disposal site.

- **Seattle route**, east on I-90 to Ellensburg, Washington, then south on I-82 through Yakima, Washington and east to I-182 to State Route 240, to the commercial LLRW disposal site.

- **Umatilla route**, from Ontario, Oregon, east on I-84 to Hermiston, Oregon and then north on I-82 to I-82, to State Route 240, to the commercial LLRW disposal site.

RADTRAN 4 models both an incident-free dose and an accident risk. The incident-free dose is from external radiation to individuals during transport of the waste. For the incident-free dose, RADTRAN 4 assumes that all U.S. DOT standards are met at the maximum allowable dose for the entire transportation route.[32]

Accident risk is based on exposure to radioactive material released as a direct result of an accident during transport. The accident risk is based on accident rate, probability of container failure, fraction of material released, chemical and physical nature of the material, radioactivity of the material, and proximity of individuals to the accident site. The probability of a traffic accident involving a truck carrying radioactive material is one accident for every 1 in 1,000,000 vehicle-miles. If an accident happens, the probability that the accident will involve a significant release of radioactive materials is less than 5%.

RADTRAN 4 Results

Transportation risks are reported separately for incident-free dose and accident risk. For individuals along the transportation corridor, the incident-free dose averages 3.8×10^{-9} mrem/year along all four routes. The average risk for exposure to these same individuals from a transportation accident is less than 1.0×10^{-8} along all four routes. This means that an individual would have a .0000001% increase of dying from cancer due to a transportation accident associated with the commercial LLRW disposal site.

[32] Experience indicates that the external dose rate is well below the regulatory limit in most shipments, and it is undetectably low for many shipments (Weiner 1998).

Transportation risks were calculated separately for NARM volumes (8,600, 50,000, and 100,000 ft^3/year). RADTRAN 4 predicted that the transport of 100,000 ft^3/year of NARM would contribute less than 1.0 $x10^{-10}$ mrem/year to the incident-free dose and have less than a 1.0 x 10^{-9} accident risk for individuals living along any of the four routes.

Although RADTRAN 4 predicts negligible future risks from accidents and incident-free exposure, the model does not consider the type of events, such as packaging violations, that have historically occurred at the commercial LLRW disposal site. Therefore, the state must consider both predicted and historic risks in assessing the impacts from License Renewal, NARM Acceptance, and Site Closure.

4.1.1.2.3 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Historic records and predicted future exposures using RADTRAN 4 indicate a very low risk to individuals from transportation associated with relicensing the commercial LLRW disposal site. The Enhanced Relicensing Alternative will increase point-of-origin inspections that, in turn, may reduce transportation risks associated with packaging violations during transport. However, denying the US Ecology License would eliminate shipments of waste to the commercial LLRW disposal site and eliminate transportation risk altogether.

Impacts of NARM Acceptance

The contribution of NARM to future transportation risks is extremely low; however, less NARM that is shipped to the site means less potential for transportation risk. Transportation risks from NARM packaging violations can be minimized further through the Enhanced Relicensing Alternative.

Impacts of Site Closure

Transportation of waste during operations is not impacted by Site Closure.

Impacts of the Filled Site Alternative

RADTRAN 4 results show that, although the overall risk is low, there is a correlation between increased waste shipments and transportation risks. This increase in transportation risk associated with increased waste shipments has not been calculated for the Filled Site Alternative.

Mitigation Measures

None suggested.

Significant Unavoidable Adverse Impacts

None identified.

4.1.1.3 Cover Construction Risk

The final cover constructed at the commercial LLRW disposal site will span at least 50 acres when complete. As with all large construction projects there will be some risk to construction workers. Potential construction risks include accidents with heavy equipment, heavy lifting, vehicle accidents and slips, trips, and falls.

Applicable Occupational Standards:

- Occupational Dose Limits of 5000 mrem/year (Chapter 246-221 WAC)
- Washington Industrial Safety and Health Act (WISHA) (RCW 49.17)

Non-radiological construction accidents will be managed through compliance with WISHA standards. The frequency and severity of accidents will depend on the safety culture and adherence with WISHA standards. None of the cover designs are considered unusual or overly dangerous to construct (WDOH 1998b). Worker exposure to radiation during cover construction is unlikely because there will be no need for exposure or handling of the waste packages by construction workers (WDOH 1998b).

4.1.1.3.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Renewing the US Ecology License result in the need for a larger cover; however, a larger cover is not expected to significantly increase construction risks.

Impacts of NARM Acceptance

NARM Acceptance limits may result in the need for a larger cover; however, a larger cover is not expected to significantly increase construction risks.

Impacts of Site Closure

The closure designs with the simplest construction, such as the Site Soils Cover and the Thick Homogenous Cover may have a lower potential for accidents. The Closure Schedule Alternatives with multiple construction periods such as the “Close-as-you-go” Alternative may pose higher risks. There is no risk from radiological exposure expected.

Impacts of the Filled Site Alternative

The Filled Site Alternative will require a significantly larger cover, more construction, and therefore may have higher construction risks.

Mitigation Measures

Standard construction practices required under WISHA.

Significant Unavoidable Adverse Impacts

None identified.

4.1.2 Long-Term Radiological Public Health Risk

This section evaluates the long-term radiological public health risk of License Renewal, NARM Acceptance, and Site Closure. “Long-term” is defined as the 10,000-year period after closure. Long-term health risk is dependent on the type and amount of waste at the site (source term), the method of closure, and the likelihood that an individual will live on or near the commercial LLRW disposal site in the future. The source term used to predict long-term health risk at the commercial LLRW disposal site is documented in *Source Term Documentation for Radiological Risk Analysis* (Thatcher and Elsen 1999).

Individuals living or working outside the boundaries of the commercial LLRW disposal site are referred to as “offsite” individuals. Impacts to the offsite individual are measured at the fenceline of the commercial LLRW disposal site. Individuals living directly on the commercial LLRW disposal site are referred to as “onsite intruders.” Onsite intruders can include both inadvertent and deliberate intruders. The inadvertent intruder is *unaware* of the closed commercial LLRW disposal site. The deliberate intruder is *aware* of the disposal site and chooses to intrude anyway. The U.S. NRC and WDOH closure regulations are written to primarily protect the inadvertent intruder. For this reason, this section only discusses impacts to the offsite person and the inadvertent intruder.

Applicable standards include:

- Offsite individual dose of 25 mrem/year (Chapter 246-250 WAC)
- Offsite ambient air dose of 10 mrem/year (Chapter 246-247 WAC)
- Four mrem/year public drinking water supply dose(Chapter 246-290 WAC)
- Closing disposal trenches as filled (Chapter 246-250 WAC)

Guidance values include:
- 500 mrem/year onsite intruder dose (10 CFR Part 61 DEIS)

Consideration values include:
- 15 mrem/year WDOH Hanford cleanup level
- One in 100,000 MTCA cleanup risk level (Chapter 173-303 WAC)
- 100 to 500 mrem/year onsite intruder radiation cleanup standards (Chapter 246-246 WAC)

This section first discusses the performance of the closure cover designs. Next, this section discusses radiation dose and risk based on cover performance and theoretical lifestyle scenarios.

4.1.2.1 Performance Assessment of Cover Designs

Long-term public health risk is strongly influenced by cover performance.[33] For this evaluation, cover performance is defined as "a cover's effectiveness in isolating the waste from the environment." Cover performance is dependent on both the cover design and the long-term reliability of that design. Table 13 shows the comparative performance of the cover designs in minimizing direct waste contact, controlling gas emanation up through the cover, and reducing water infiltration.

Table 13: Comparative Performance of Closure Cover Designs

Closure Cover Designs	Potential for Direct Waste Contact	Control of Gas Emanation	Water Infiltration Rate[34]
US Ecology Proposed Cover	Low	High	2.0 mm*/year
Site Soils Cover	Moderate	Low	20 mm/year
Thick Homogenous Cover	Low	Moderate	0.5 mm/year
Enhanced Asphalt Cover	Low	High	0.5 mm/year
Enhanced Synthetic Cover	Low	Moderate	0.5 mm/year
Enhanced Bentonite Cover	Low	High	0.5 mm/year
Filled Site Alternative w/ US Ecology Proposed Cover	Same as US Ecology Proposed Cover	Same as US Ecology Proposed Cover	Same as US Ecology Proposed Cover

*mm = millimeter

4.1.2.1.1 Direct Waste Contact

Preventing direct waste contact is one performance objective of a cover. The probability of a person, animal, or plant coming into direct contact with the waste is controlled by the thickness of the cover and by the materials in the cover. Covers at least five meters thick are expected to be effective at preventing direct contact[35] (U.S. NRC 1982)**.** All of the cover design alternatives, except the Site Soils Cover, are at least five meters thick. Materials such as asphalt may also control direct contact by forming a physical barrier to well drilling or excavation.

4.1.2.1.2 Gas Emanation

Minimizing gas emanation is another performance objective for a cover. Gas emanation through the cover designs was modeled for 10,000 years post-closure (Thatcher

[33] This section on public health focuses on cover performance. In the approved Closure Plan, there will be other aspects of closure such as surface decontamination and institutional controls that have the potential to mitigate overall risk. These other aspects were not included in this section because they are assumed to be consistent among all closure alternatives and therefore would not be significant for purposes of comparing alternatives.

[34] Water infiltration through the Thick Homogenous and Enhanced Covers was predicted to be less than .001 mm/year infiltration. However, in order to be conservative, a rate of 0.5 mm/year was used in the modeling.

[35] Cover depth will not protect an onsite intruder who is deliberately trying to get to the waste. Cover depth will also not protect an onsite intruder drilling a well through the cover and into the waste.

2000a). The modeling showed that gas emanation is primarily a concern for the onsite intruder and, due to atmospheric dispersion, has only minimal impacts to the offsite individual. Radon, carbon 14, and tritium were found to be the three nuclides most likely to emanate through the cover designs (Thatcher 2000a). Of these three nuclides, radon gas is the most significant.

Cover depth, cover materials, and cover permeability are the key cover characteristics for controlling gas emanation. A deep cover with fine-grained soils such as silts or clays will minimize gas emanation. All of the low-permeability barriers will also help control gas emanation but as the barriers degrade, their ability to control emanation will be reduced. For gas emanation, the asphalt and bentonite low-permeability barriers were given a moderate degradation factor. The synthetic low-permeability barrier was given a 100% degradation factor based on the low probability the high density polyethylene (HDPE) material would be effective after 500 years (Thatcher 2000a). The assumption of a 100% degradation factor makes the synthetic low-permeability barrier completely ineffective for the control of gas emanation.

Based on cover depth, soil types, and the assumed degradation of the low-permeability barriers, the US Ecology Proposed Cover, Enhanced Asphalt Cover, and Enhanced Bentonite Cover are rated high in Table 13 for control of gas emanation. The Enhanced Synthetic Cover and the Thick Homogenous Cover are rated moderate for control of gas emanation and the Site Soils Cover is rated low.

Predicting gas emanation rates is highly dependent on the assumptions made about the degradation of the low-permeability barriers. In addition, there are many other cover performance unknowns affecting gas emanation. For these reasons, the cover designs may, in practice, show higher or lesser performance for controlling gas emanation (Thatcher 2000a).

4.1.2.1.3 Infiltration Rates and Groundwater Concentrations

Minimizing the leaching of contaminants to the groundwater is another performance objectives of the cover. The performance of a cover in controlling infiltration at the commercial LLRW disposal site is key in preventing groundwater contamination. Infiltration rates and predicted groundwater radionuclide concentrations for the cover designs are reported in *Groundwater Pathway Analysis for the Commercial LLRW Low-Level Radioactive Waste Site, Washington Department of Health* (Dunkelman 2000). This report is attached as Appendix III. The information in this section is all referenced to the above report unless noted otherwise.

UNSAT-H, a numeric model, was used to predict infiltration through the cover designs (Fayer and Jones, 1990). A second model, GWSCREEN, used the UNSAT-H results to predict future radionuclide concentrations in groundwater (Rood 1994). Numerous assumptions and simplifications were required for both modeling efforts. These include:

- amount of vegetation growth on the covers
- longevity and integrity of waste packaging
- subsidence and settlement of the waste
- period of time filled trenches will be left without a low-permeability cover, and
- long-term reliability of the cover designs.

UNSAT-H Modeling

In UNSAT-H, the cover characteristics most important for controlling infiltration are percent gravel, percent silt, and depth of the upper silt loam layer. Table 13 shows that UNSAT-H predicted the Enhanced Covers and the Thick Homogenous Cover would have the lowest infiltration rates, the Site Soils Cover would have the highest infiltration rate, and the US Ecology Proposed Cover would have an infiltration rate in-between.

For the US Ecology Proposed Cover, the Thick Homogenous Cover, and the Enhanced Cover Designs, UNSAT-H was only used to model those layers, down to but not including the low-permeability barrier. The UNSAT-H modeling did not consider the low-permeability barriers or layers below the barriers because infiltration rates through the cover, above those barriers, were predicted to be almost negligible.

UNSAT-H modeled the covers as they were designed and did not consider any reduction in performance due to such possible conditions as settlement, cracking, degradation of cover materials, clogging of gravel drain layers, burrowing by animals, destruction of vegetation, intrusion of deep rooted plants, accumulation of windblown material onsite, or erosion due to wind. These conditions determine the long-term reliability of a cover design, and their potential impact on performance must be weighed in the overall evaluation and ranking of the alternative covers. The assumptions, simplifications, and limitations for UNSAT-H are discussed in Appendix III. Future performance monitoring of the cover designs will be used to help verify the assumptions and results for the UNSAT-H modeling.

GWSCREEN Modeling

GWSCREEN was used to predict concentrations of radionuclides in groundwater for 10,000 years after site closure. The five nuclides shown to impact groundwater are chlorine 36 (Cl-36), technetium 99 (Tc-99), iodine 29(I-129), uranium 235 (U-235), and uranium 238 (U-238). Gross beta, a measure of beta emitting nuclides, was also examined because it is a screening tool for drinking water and groundwater. Table 14 lists the predicted maximum concentrations in the groundwater for the five nuclides and gross beta. Concentrations reported in Table 14 are for both onsite and offsite groundwater.

Table 14: GWSCREEN Maximum Groundwater Concentrations (through 10,000 Years)

Cover Design	Closure Date	Gross Beta[36] pCi/L	Cl-36 pCi/L	Tc-99 pCi/L	I-129 pCi/L	U-235 pCi/L*	U-238 pCi/L*
US Ecology Proposed Cover	**2056**	180	36	490	3.9	0.23	0.036
Site Soils Cover	**2000**	220	45	580	4.6	2.3	0.36
Thick Homo-genous Cover	**2056**	101	20	272	1.9	0.057	0.0089
Enhanced Covers	**2056**	101	20	272	1.9	0.057	0.0089
Enhanced Bentonite Cover	**2000**	95	19	250	1.8	0.057	0.0089
Filled Site Alternative w/ US Ecology Proposed Cover	**2215**	216	38	590	4.5	2.3	0.36

* These concentrations are increasing at 10,000 years

As expected, the cover designs with the highest infiltration rates result in the highest groundwater concentrations. GWSCREEN predicted only a minor increase in groundwater concentrations between closing the site in the year 2000 and closure in the year 2056.[37] This increase is minor because the majority of waste containing Cl-36, Tc-99, I-129, U-235, and U-238 has already been disposed at the commercial LLRW disposal site. Future disposal rates of wastes containing these radionuclides are expected to be much lower than in the past. In other words, future groundwater radionuclide concentrations will be primarily a result of waste already disposed, not of waste expected to be disposed in the future.

Numerous assumptions and simplifications were used to predict groundwater concentrations. The assumptions and simplifications for GWSCREEN are discussed in Appendix III. Future groundwater and vadose monitoring can be used to help verify some of the assumptions and results for the GWSCREEN modeling.

[36] Gross Beta was not predicted directly through GWSCREEN. It was calculated based on the individual nuclide concentrations.
[37] This increase is calculated by comparing groundwater concentrations for the Enhanced Covers and Enhanced Bentonite Cover for the two closure dates of year 2000 and year 2056 (see Table 17).

4.1.2.1.4 Long-Term Reliability of Cover Designs

Reliability of a cover will affect its long-term performance. A cover design with moderate performance but high reliability may be a better choice than one with high performance and low reliability. Environmental stresses such as erosion, subsidence, biological intrusion, range fires, extreme weather, and human intrusion can affect a cover's long-term performance. Other than including a degradation factor for low-permeability barriers in the gas emanation calculations, long-term reliability was not quantitatively considered in determining cover performance. Cover reliability was considered in a subsequent uncertainty analysis, but that analysis was for information purposes only and is not considered in this DEIS.

There are differing opinions on how well a cover design can withstand environmental stresses. One difference is on whether or not a low-permeability barrier increases or decreases the reliability of a cover. Although a low-permeability barrier can provide a second level of infiltration control, the barrier may eventually fail or deform due to subsidence of the waste, and other environmental stresses. This failure, depending on its severity, may render a low-permeability barrier ineffective and reduce the overall performance through cracking or discontinuity of the layers in the cover. There is particular concern over the long-term reliability of asphalt as a low-permeability barrier because its physical characteristics may make it exceptionally vulnerable to environmental stresses. Due to these uncertainties, some professionals support the use of a more homogenous low-permeability soil cover. At this time, there is no conclusive evidence to fully support either opinion. Future monitoring may provide more knowledge on the long-term reliability of the different cover designs.

4.1.2.2 Impacts of Closure Schedule Alternatives

The closure schedule can increase waste isolation during the operations period. The impact that the closure schedule alternatives might have on long-term public health was not quantified. However, constructing parts of the final cover early will not only provide early waste isolation, it will provide a 50-year observation period and an opportunity to gain knowledge on cover design performance and reliability. The Close-as-you-go Schedule, US Ecology Proposed Schedule, and the Prototype Schedule all provide some early construction of the final cover.

4.1.2.3 Radiation Dose to the Individual

Radiation doses for the 10,000-year post-closure period were calculated in *WDOH Radiological Risk Assessment for the Commercial Low-Level Radiological Waste Site* (Thatcher 2000a). This report, referred to as the WDOH Risk Assessment, is attached as Appendix II. All results and discussion in this section, unless specified otherwise, are referenced to the WDOH Risk Assessment.

Hypothetical land-use and lifestyle scenarios, described in Table 15, were used to determine an individual's potential exposure to nuclides in the water, air, soil, and vegetation during the 10,000 year post-closure period.

Table 15: Lifestyle Scenarios

Scenario	Location of exposure	Time of Exposure*	Special Considerations
Offsite Rural Resident	Disposal site boundary	30 years adults 30 years children	Builds a home at the commercial LLRW disposal site boundary in the predominant downwind and downgradient direction. Spends 100% of time at home. Drills water well for drinking water and domestic uses. Grows a portion of own food.
Offsite Native American	Disposal site boundary	70 years adult 70 years child	Similar to offsite rural resident with increased production of food crops, sweatlodge use, and longer residency time.
Onsite Intruder Rural Resident	Throughout disposal site	30 years adult 30 years child	Takes up residence on commercial LLRW disposal site. Lifestyle similar to offsite resident, except a water well is drilled through the waste and the spoils are spread on the surface.
Onsite Intruder Native American	Throughout disposal site	70 years adult 70 years child	Takes up residence on commercial LLRW disposal site and lives entire life onsite. Lifestyle similar to the offsite Native American, except a water well is drilled through the waste and the spoils are spread on the surface. Spends less time indoors than the Rural Resident.
Onsite Intruder Construction Worker – Well Driller	Throughout disposal site	40 hours	Temporary time spent on commercial LLRW disposal site. Drills a well for onsite resident intruder.
Onsite Intruder Construction Worker - Home Builder	Throughout disposal site	500 hours	Temporary time spent on commercial LLRW disposal site. Builds a home, including excavation for onsite resident intruder.

*See Radiological Risk Assessment (Thatcher 2000a) for explanation of exposure time.

4.1.2.3.1 Dose Assessment

The WDOH Risk Assessment selected representative combinations of License Renewal, NARM Acceptance, and Cover Design Alternatives to predict an individual's future dose and their risk from that dose. All cover designs except the Site Soils Cover are evaluated for closure in year 2056. The Site Soils Cover was only evaluated for closure in the year 2000.[38] The Enhanced Bentonite Cover is evaluated for closure both in the years 2000 and year 2056 in order to provide a comparison of impacts between relicensing the site and closing the site. Neither the Enhanced Licensing

[38] The Site Soils Cover was only evaluated for closure in year 2000, based on the assumption that the Site Soils Cover would only be constructed if the site were closed suddenly with no approved closure plan.

alternative nor any of the closure schedule alternatives were considered quantitatively in the WDOH Risk Assessment.

Ambient Air Dose

The ambient air dose is the dose attributed to the commercial LLRW disposal site from breathing or inhaling air contaminants during normal daily. Table 16 lists the maximum ambient dose predicted for the 10,000-year post-closure period. The primary contributor to this dose is radon, followed by carbon 14 and tritium.[39]

Table 16: Maximum Air Pathway Dose Through 10,000 Years*

Closure Cover Design	Closure Date	Maximum Ambient Offsite Air Dose mrem/year	Maximum Ambient Onsite Air Dose mrem/year[40]
Proposed US Ecology Cover	2056	2.9	4.3
Site Soils Cover	2000	9.3	15
Thick Homogenous Cover	2056	4.5	6.9
Enhanced Asphalt Cover	2056	0.91	1
Enhanced Synthetic Cover	2056	4.7	7.4
Enhanced Bentonite Cover	2056	2.8	4.1
Enhanced Cover Bentonite – Year 2000	2000	1.9	2.8
Filled Site Alternative with US Ecology Proposed Cover	2215	4.5	7.6

*Based on NARM volume of 36,700 ft^3/year

All closure cover designs, except the Site Soils Cover, meet the 10-mrem/year ambient air standard (Chapter 246-247 WAC). The Enhanced Asphalt and Enhanced Bentonite Cover are the most effective at protecting the ambient air quality due to their low-permeability barriers.[41] Comparing the predicted individual ambient air dose for the Enhanced Bentonite Cover for closure in the year 2000 and the year 2056 shows an increase that can be attributed to relicensing the site of 0.9 mrem/year offsite and 1.3 mrem/year onsite. The Filled Site Alternative compared to the US Ecology Proposed Cover shows an offsite increase of 1.6 and an onsite increase of 3.3 mrem/year. This increase can be attributed to the increased source term of the Filled Site Alternative.

Drinking Water Dose

Ingesting drinking water is another means an individual might be exposed to radionuclides at the commercial LLRW disposal site.[42] Drinking water was evaluated to determine compliance with drinking water standards. Public Water Supply regulations

[39] The dose in Table 14 was calculated using the U.S. EPA COMPLY code.
[40] This does not include exposure to indoor radon.
[41] The air pathway evaluation for regulatory compliance with the 10-mrem/year ambient standard does not include well drilling material brought to the surface.
[42] Drinking water is only one pathway of the total groundwater dose. Other pathways for groundwater include inhalation of water vapor and ingestion of plants irrigated with groundwater.

(Chapter 246-290 WAC) contain a four-mrem/year standard for drinking water that applies for 1000 years post-closure.

Compliance with the four-mrem/year standard can be evaluated by comparing maximum contaminant levels (MCLs) with the predicted groundwater concentrations of the individual nuclides predicted to reach the groundwater within the 1000 year post-closure period (U.S. EPA 1976).[43] The predicted concentrations are the same for both onsite and offsite groundwater. As shown in Table 17, none of the cover designs exceed the MCLs of the individual radionuclides, therefore, satisfying the four-mrem/year standard.

Table 17: Comparison of MCLs with Maximum Groundwater Concentrations for Cl-36, Tc-99 and I-129 (pCi/L)* (through 1000 years)

Radionuclide		**Cl-36**	**Tc-99**	**I-129**
Maximum Contaminant Levels (MCLs)		**700**	**900**	**1**
Closure Cover Design	**Closure Date**			
US Ecology Proposed Cover	**2056**	36	490	0
Site Soils Cover	**2000**	46	580	0
Thick Homogenous Cover	**2056**	20	270	0
Enhanced Asphalt Cover	**2056**	20	270	0
Enhanced Synthetic Cover	**2056**	20	270	0
Enhanced Bentonite Cover	**2056**	20	270	0
Enhanced Bentonite Cover	**2000**	19	250	0
Filled Site Alternative w/ US Ecology Proposed Cover	**2056 or 2215**	38	590	0

* Based on NARM volume of 36,700 ft^3/year

Total Effective Dose Equivalent (TEDE)

The TEDE measures the total dose from all pathways to the whole body. This includes the air pathway, drinking water pathway, food pathway, and direct contact with the waste. Tables 18a and 18b list the maximum individual dose expected during the 10,000-year post-closure period. The doses shown in Tables 18a and 18b are based on a NARM volume of 36,700 ft^3/year.

[43] Contributions from uranium are excluded from National Primary Drinking Water Standards (40 CFR part 141).

Table 18a: Maximum Offsite Dose Through 10,000 Years * (mrem/year)

Scenario	Proposed and Alternative Cover Designs							
	Proposed US Ecology Cover	Filled Site Alternative	Site Soils Cover	Thick Homo-genous Cover	Enhanced Asphalt Cover	Enhanced Synthetic Cover	Enhanced Bentonite Cover	Enhanced Bentonite Cover
Closure Date	**2056**	**2056 or 2215**	**2000**	**2056**	**2056**	**2056**	**2056**	**2000**
Rural Resident Adult	8	12	20	9	2.7	9.0	5.8	4.4
Rural Resident Child	12	16	25	11	5.3	12	8.4	6.9
Native American Adult	12	16	32	11	5.2	12	8.3	6.2
Native American Child	18	23	32	15	8.7	15	12	10

* Based on NARM volume of 36,700 ft^3/year

Table 18b: Maximum Dose for Onsite Intruders Through 10,000 Years* (mrem/year)

Scenario	Proposed and Alternative Cover Designs and Closure Dates							
	Proposed US Ecology Cover	Filled Site Alterna-tive	Site Soils Cover	Thick Homogen-ous Cover	Enhanced Asphalt Cover	Enhanced Synthetic Cover	Enhanced Bentonite Cover	Enhanced Bentonite Cover
Closure Date	**2056**	**2056 or 2215**	**2056**	**2056**	**2056**	**2056**	**2056**	**2000**
Rural Resident Adult	310	520	950	440	93	470	280	210
Rural Resident Child	310	520	950	440	93	470	280	210
Native American Adult	280	460	830	390	91	410	250	190
Native American Child	280	460	820	390	91	410	250	190
Construc-tion Well Driller	1.9	1.9	2.3	2	1.8	2	1.9	2
Construc-tion Home Builder	22	22	26	23	21	24	22	22

*Doses for rural residents and Native Americans are shown as per year. Doses for the well driller and homebuilder are one-time events.
*Based on NARM volume of 36,700 ft^3/year

The offsite dose is split fairly evenly between the groundwater pathway and the air pathway. The groundwater pathway includes drinking water, ingestion during showers, and eating locally grown food irrigated with groundwater. The air pathway includes breathing both the outside air and air inside a home. All cover designs except the Site Soils Cover meet or exceed the 25-mrem/year individual dose limit for closure in Chapter 246-250 WAC. Only the Enhanced Asphalt Cover and Enhanced Bentonite Cover meet the 15-mrem/year WDOH guidance value for Hanford.

Comparing the offsite dose for the Enhanced Bentonite Cover for closure in the year 2000 and the year 2056 shows an increase of less than two mrem/year that can be attributed to relicensing the site. The Filled Site Alternative is predicted to result in an additional increase of five mrem/year due to increased source term.

The onsite dose is higher than the offsite dose and is due primarily to the potential exposure to indoor radon. The Rural Resident Adult is expected to spend more time indoors and is exposed to more indoor radon, thereby receiving a higher onsite dose than the Native American Adult. Comparing the onsite intruder dose for the Enhanced

Bentonite Cover for closure in the year 2000 and for closure in the year 2056 shows an increase of up to 70 mrem/year that can be attributed to renewing the US Ecology License. All cover designs, except the Site Soils Cover, are below the 500-mrem/year onsite intruder guidance. However, only the Enhanced Asphalt Cover is below the 100-mrem/year level of the 100/500-mrem/year consideration value recently adopted in the Radiation Cleanup Standards (Chapter 246-246 WAC).[44] The cover design alternatives have very little impact on the dose to the construction well driller or construction home builder, because these individuals are assumed to spend a relatively short time onsite. The Filled Site Alternative increases the onsite dose by a maximum of 210 mrem/year.

4.1.2.3.2 NARM Contribution to Dose

This section discusses the impacts of NARM volumes on the rural resident onsite intruder dose.[45] Previously, Tables 18a and 18b used an average NARM volume of 36,700 ft^3/year. Table 19 lists onsite intruder doses for NARM volumes of 8,600; 36,700; and 100,000 ft^3/year. Similar to the previous doses, these doses represent the total dose from both low-level waste and NARM.

Table 19: Maximum Onsite Intruder Dose to the Rural Resident Adult for Different NARM Volumes Through 10,000 Years (mrem/year)

Closure Cover Design	Closure Date	Onsite Intruder Dose mrem/year		
		8,600 ft^3/year	36,700 ft^3/year	100,000 ft^3/year
Proposed US Ecology Cover	**2056**	260	310	420
Site Soils Cover	**2000**	930	950	1000
Thick Homogenous Cover	**2056**	370	440	610
Enhanced Asphalt Cover	**2056**	81	93	120
Enhanced Synthetic Cover	**2056**	390	470	650
Enhanced Bentonite Cover	**2056**	240	280	390
Enhanced Bentonite Cover	**2000**	180	210	260
Filled Site w/ US Ecology Proposed Cover	**2056 or 2215**	350	520	910

Increasing or decreasing NARM volumes impact the onsite intruder dose primarily because of the predicted indoor radon exposure. For a NARM volume of 100,000 ft^3/year, the onsite intruder dose exceeds the 500 mrem/year guidance when the site is closed with the Site Soils Cover, Thick Homogenous Cover, and Enhanced Synthetic Cover. For a NARM volume of 8,600 ft^3/year and 36,700 ft^3/year, the onsite intruder dose of 500 mrem/year is only exceeded when the site is closed with the Site Soils

[44] The Radiation Cleanup Standards are not a mandatory or guidance level because commercial low-level radioactive disposal sites are specifically exempt from these standards.
[45] The impacts of different NARM volumes on the offsite dose were not calculated due to the minor impact of NARM on offsite doses. The Rural Resident Adult scenario was selected because this scenario results in the highest onsite intruder doses from NARM.

Cover. The Filled Site Alternative only meets the 500-mrem/year onsite intruder guidance when a NARM volume of 8,600 ft^3/year is considered. With the exception of the Enhanced Asphalt Cover, all cover designs and NARM volumes exceed the 100-mrem/year level of the100/500 mrem/year consideration value.

4.1.2.4 Radiological Cancer Risk

Radiological risk was calculated based on the doses reported in Tables 18a and 18b. The risk reported in Tables 20a and 20b is the additional risk of fatal cancer for an individual who is exposed to the commercial LLRW disposal site during the 10,000 year post-closure period[46] (ICRP 60 1990).

Table 20a: Maximum Lifetime Risk for Offsite Individuals Through 10,000 Years*

Scenario	Cover Designs and Closure Date							
	US Ecology Proposed Cover	**Filled Site Alterna-tive**	**Site Soils Cover**	**Thick Homo-genous Cover**	**Enhanced Asphalt Cover**	**Enhanced Synthetic Cover**	**Enhanced Bentonite Cover**	**Enhanced Bentonite Cover**
Closure Date	**2056**	**2056 or 2215**	**2000**	**2056**	**2056**	**2056**	**2056**	**2000**
Rural Resident Adult	1.2×10^{-4}	1.7×10^{-4}	3×10^{-4}	1.3×10^{-4}	4.0×10^{-5}	1.4×10^{-4}	8.7×10^{-5}	6.6×10^{-5}
Rural Resident Child	1.3×10^{-4}	1.9×10^{-4}	3×10^{-4}	1.4×10^{-4}	4.8×10^{-5}	1.4×10^{-4}	9.5×10^{-5}	7.3×10^{-5}
Native American Adult	4.2×10^{-4}	5.8×10^{-4}	1.1×10^{-3}	3.9×10^{-4}	1.8×10^{-4}	4.1×10^{-4}	2.9×10^{-4}	2.2×10^{-4}
Native American Child	4.4×10^{-4}	6.0×10^{-4}	1.1×10^{-3}	4.0×10^{-4}	2.3×10^{-4}	4.2×10^{-4}	3.1×10^{-4}	2.3×10^{-4}

*Based on NARM Volume of 36,700 ft^3/year

[46] Although risk was calculated for 10,000 years, the state recognizes that considerable uncertainty exists for projections greater than 1,000 years, due predominately to the uncertainty in groundwater modeling.

Table 20b: Maximum Lifetime Risk for Onsite Intruders Through 10,000 Years*

Scenario	Proposed and Alternative Cover Designs and Closure Date							
	US Ecology Proposed Cover	Filled Site Alterna-tive	Site Soils Cover	Thick Homo-genous Cover	Enhanced Asphalt Cover	Enhanced Synthetic Cover	En-hanced Bentonite Cover	En-hanced Bentonite Cover
Closure Date	**2056**	**2056 or 2215**	**2000**	**2056**	**2056**	**2056**	**2056**	**2000**
Rural Resident Adult	4.6×10^{-3}	7.8×10^{-3}	1.4×10^{-2}	6.7×10^{-3}	1.4×10^{-3}	7.0×10^{-3}	4.3×10^{-3}	3.2×10^{-3}
Rural Resident Child	4.6×10^{-3}	7.8×10^{-3}	1.4×10^{-2}	6.7×10^{-3}	1.4×10^{-3}	7.0×10^{-3}	4.3×10^{-3}	3.2×10^{-3}
Native American Adult	9.7×10^{-3}	1.6×10^{-2}	2.9×10^{-2}	1.4×10^{-2}	3.2×10^{-3}	1.4×10^{-2}	8.8×10^{-3}	6.7×10^{-3}
Native American Child	9.7×10^{-3}	1.6×10^{-2}	2.9×10^{-2}	1.4×10^{-2}	3.2×10^{-3}	1.4×10^{-2}	8.9×10^{-3}	6.7×10^{-3}
Con-struction Well Driller	9.5×10^{-7}	9.5×10^{-7}	1.2×10^{-6}	1.0×10^{-6}	9.0×10^{-7}	1.0×10^{-6}	9.5×10^{-7}	1.0×10^{-6}
Con-struction Home Builder	1.1×10^{-5}	1.1×10^{-5}	1.3×10^{-5}	1.2×10^{-5}	1.1×10^{-5}	1.2×10^{-5}	1.1×10^{-5}	1.1×10^{-5}

* Based on NARM Volume of 36,700 ft^3/year

Risk to the Native American is highest due to their hypothetical lifestyle. This higher risk is predicted even though the Native American does not receive the highest dose. The higher risk to the onsite Native American is because their lifestyle scenario assumed a 70-year residency onsite, compared to the rural resident scenario that only assumed a 30-year residency onsite. If the residency times were assumed equal for both Native Americans and non-Native Americans, risks would be higher for the non-Native American. Risks to children are highest within both lifestyle scenarios.

As expected, the Site Soils Cover results in the highest onsite and offsite risk, and the Enhanced Asphalt Cover results in the lowest. For closure in year 2056, the risk for an offsite Native American is 1.1×10^{-3} for closure with the Site Soils Cover, and 2.3×10^{-4} for closure with the Enhanced Asphalt Cover. This predicted risk theoretically means that if a Native American lives adjacent to the closed commercial LLRW disposal site for 70 years, he or she has an additional one in 900 (0.1%) to one in 4,300 (0.02%) chance of fatal cancer depending on what cover design is used.

For closure in the year 2056, maximum risk predicted for the Native American onsite intruder is 2.9×10^{-2} for closure with the Site Soils Cover and 3.2×10^{-3} if the site is closed with the Enhanced Asphalt Cover. This predicted risk theoretically means that if a Native American was living on the closed commercial LLRW disposal site for 70 years, he or she has an additional 3 in 100 (3%) to 1 in 300 (0.3%) chance of fatal cancer. Significantly lower risks are predicted for the Construction Well Driller and HomeBuilder because of their limited time spent onsite.

Although it is tempting to look at the risk values as accurately predicting impacts to public health, there are many uncertainties in a risk assessment that could affect the actual individual risk at the commercial LLRW disposal site. To minimize the chance of under-estimating the risk, conservative to very conservative assumptions were used. The methodologies used have inherent limitations and may contribute to over or under-estimating of actual risk. For these reasons, the above risk predictions are used only to compare relative risks of the alternatives, and should not be considered an assessment of actual risk. Refer to Appendix II for a full explanation of assumptions and uncertainties associated with the risk assessment.

Table 21 summarizes the maximum offsite dose, onsite dose, and lifetime risk for the cover design alternatives.

Table 21: Summary of Long-Term Impacts on Public Health*

Closure Cover Design	Closure Date	Offsite Dose mrem/Year	Onsite Dose mrem/Year	Offsite Risk	Onsite Intruder Risk
US Ecology Proposed Cover	**2056**	18	310	4.4×10^{-4}	9.7×10^{-3}
Site Soils Cover	**2000**	32	950	1.1×10^{-3}	2.9×10^{-2}
Thick Homogenous Cover	**2056**	15	440	4.0×10^{-4}	1.4×10^{-2}
Enhanced Asphalt Cover	**2056**	8.7	93	2.3×10^{-4}	3.2×10^{-3}
Enhanced Synthetic Cover	**2056**	15.0	470	4.2×10^{-4}	1.4×10^{-2}
Enhanced Bentonite Cover	**2056**	12	280	3.1×10^{-4}	8.9×10^{-3}
Enhanced Bentonite Cover	**2000**	10	210	2.3×10^{-4}	6.7×10^{-3}
Filled Site Alternative/w US Ecology Proposed Cover	**2056 or 2215**	23	520	6.0×10^{-4}	1.6×10^{-2}

* Dose and Risk values are based on NARM volumes of 36,700 ft^3/year and represent the maximum value within the 10,000-year post-closure period for the most sensitive lifestyle.

4.1.2.5 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

All License Renewal impacts described in this summary represent the most sensitive lifestyle scenario, a NARM volume of 36,700 ft^3/year, and closure with the Enhanced Bentonite Cover.

Renewing the US Ecology License is not predicted to cause the onsite or offsite ambient air dose to exceed the 10-mrem/year standard at any time during operations or post-closure, as shown in Table 16. Renewing the US Ecology License is predicted to result in only minor increases in concentrations of both offsite and onsite groundwater. Table 17 shows that renewing the US Ecology License will not result in the drinking water dose exceeding the four-mrem/year public water supply standard.

Total doses to the offsite individual and onsite intruder are shown in 16a and 16b. License renewal has a small impact on the offsite dose. A 10-mrem/year dose to the Native American Child is predicted if the US Ecology License is denied. That dose would increase by 2 mrem/year (20%) if the US Ecology License were renewed. License renewal has a larger impact predicted to the onsite intruder. A 210-mrem/year dose to the Rural Resident Adult is predicted if the US Ecology License is denied. That dose would increase by 70 mrem/year (33%) if the US Ecology License were renewed.

Although impacts from renewal of the US Ecology License were only quantified for the Enhanced Bentonite Cover, some conclusions can be drawn concerning relicensing impacts associated with the other cover design alternatives. For covers predicted to perform less effectively than the Enhanced Bentonite Cover, such as the US Ecology Proposed Cover, the Thick Homogenous Cover, and the Enhanced Synthetic Cover, the above increases attributed to relicensing would be proportionally higher. The Enhanced Asphalt Cover is predicted to perform better than the Enhanced Bentonite Cover, and therefore dose or risk increases attributed to relicensing would be proportionally lower.

Impacts or benefits of the Enhanced Relicensing Alternative were not quantified. However, the enhanced practices selected for this alternative were all based on providing either improved waste isolation or improved worker safety and, are therefore, expected to reduce the total individual dose.

Impacts of NARM Acceptance

Long-term health impacts from NARM are primarily to the onsite intruder who is exposed to radon that has been concentrated in a basement or sweatlodge. NARM impacts are strongly influenced by cover design and volumes as shown in Table 19. These results show that the NARM impact on long-term health can be controlled, in part, by selecting a cover design with a reliable low-permeability barrier.

Impacts of Site Closure

Cover design is a key factor in controlling long-term impacts to public health. Cover design performance compared in Table 13 shows that the Enhanced Asphalt Cover ranks the highest, followed by the Enhanced Bentonite Cover, US Ecology Proposed Cover, Thick Homogenous Cover, Enhanced Synthetic Cover, and Site Soils Cover. This comparison did not fully consider long-term reliability of the cover designs. The agencies recognize that more information is needed on long-term reliability to support estimates of long-term cover performance.

Closure of the commercial LLRW disposal site must comply with the 10-mrem/year ambient air quality standard, the four-mrem/year drinking water standard, and the 25-mrem/year offsite individual dose standard. All cover designs, except the Site Soils Cover, were predicted to meet these standards as shown in Table 16 and Table 18a. For the onsite intruder, compliance with the 500-mrem/year guidance value is strongly influenced by both cover design and NARM volumes as shown in Table 18b and Table19.

There are no mandatory requirements for risk. The MTCA 1 x 10^{-5} risk standard is a consideration value for this DEIS evaluation. None of the cover designs are predicted to meet this risk level for the hypothetical rural resident or Native American as shown in 18a and 18b.

The Close-as-you-go Schedule, US Ecology Proposed Schedule, and the Prototype Schedule all provide some early waste isolation, thereby potentially reducing doses during the 10,000 year post-closure period. These three alternatives also partially satisfy the requirement that a low-permeability barrier be placed over the disposal trenches as they are filled with waste (Chapter 246-250 WAC). However, early construction of a final cover may commit the agencies to a cover design that is not tested adequately and that may prove to be unreliable in the long term. A reasonable approach may be to construct a less costly low-permeability *interim* cover during the operations period, and then place a final cover in the year 2056. This would minimize infiltration and allow a longer timeframe to determine reliability of the different cover designs.

Impacts of the Filled Site Alternative

The Filled Site Alternative increases dose to the offsite individual by a maximum of 5 mrem/year, and to the onsite intruder by 210 mrem/year. The Filled Site Alternative meets all mandatory requirements but exceeds the 500-mrem/year guidance value for the Onsite Intruder.

Mitigation Measures

- Select a Closure Cover Design with high performance and high reliability.
- Select a Closure Cover Schedule that maximizes early isolation of waste.
- Select a NARM Acceptance level that will minimize dose to the onsite intruder.
- Use enhanced post-closure institutional controls to deter onsite intruders.

- Use enhanced disposal practices for NARM, including a dedicated trench and deeper burial of NARM waste.
- Immediately construct a low-permeability interim cover over all filled trenches to minimize infiltration during operations and comply with Chapter 246-250 WAC requiring each disposal trench be covered as it is filled.
- Conduct performance and reliability monitoring of early constructed covers including monitoring of infiltration rates, subsidence, vegetative growth, erosion, and reliability of cover designs to ensure predicted performance levels.
- Conduct enhanced environmental monitoring to validate groundwater modeling assumptions and conclusions.

Significant Unavoidable Adverse Impacts

Some cover designs and NARM Acceptance combinations will exceed the 25-mrem/year offsite standard and 500-mrem/year onsite intruder guidance level. These impacts can be mitigated by not selecting those cover design/NARM Acceptance combinations. All cover designs and NARM Acceptance combinations will increase the risk of fatal cancer to individuals.

4.1.3 Risk from Non-Radioactive Hazardous Waste

This section discusses the long-term health impacts from past disposal of non-radioactive hazardous waste as reported in the *Final Chemical Risk Assessment for the Commercial Low-Level Radioactive Waste Disposal Facility* (Kirner 1999). The Chemical Risk Assessment was completed before the US Ecology Site Investigation (see Section 2.5). As a result, none of the data from the US Ecology Site Investigation was considered in the Chemical Risk Assessment. Instead, the Chemical Risk Assessment relied on a combination of previously obtained sampling data, characteristics of mixed waste obtained from the National Profile on Commercially Generated Low-Level Radioactive Mixed Waste (ORNL 1992), and information on contaminants in soil and groundwater at the Maxey Flats low-level radioactive waste disposal site. This information was then used to estimate potential future risk from non-radioactive hazardous waste at the commercial LLRW disposal site.

Although the risk assessment was designed in a conservative manner to ensure the risks were thoroughly considered, it is important to recognize that the results of the chemical risk assessment should be considered cursory, due to inherent uncertainties associated with the assessment. These uncertainties include:

- Incomplete records for chemicals disposed at the commercial disposal site
- Lack of chemistry data for characterizing disposed chemicals
- An assumption that all of the contaminants remain present at the maximum concentration for the 70-year period
- The inability to model the inorganic chemical transport that may result in an under estimation of concentrations in the groundwater.

The Chemical Risk Assessment assumed and evaluated the same lifestyle scenarios as the WDOH Radiological Risk Assessment described in the previous section. A conservative infiltration rate three times greater than the Site Soils Cover was used to predict impacts on groundwater.[47]

The Chemical Risk Assessment showed no unacceptable public health risks from exposure to contaminated soil. The chemical phenol was the only contaminant in soil expected to be above a risk based concentration, but based on its rapid rate of biodegradation, it is not expected to pose an unacceptable risk to the Native American onsite intruder[48] (Kirner 1999). For groundwater, vinyl chloride is the only contaminant expected to be above a risk-based concern. It is expected that as vinyl chloride is released to the soil, it will volatize to the atmosphere within one year. Based on this high volatilization rate, risk to the Native American onsite intruder is less than $1x10^{-6}$, or an increased risk of cancer of less than one in one million (Kirner 1999).

4.1.3.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

There are no additional impacts from renewing the US Ecology License because there will be no more non-radioactive hazardous chemicals disposed at the commercial LLRW disposal site.

Impacts of NARM Acceptance

There are no additional non-radioactive hazardous risks predicted from disposal of NARM volumes because NARM is a radioactive waste.

Impacts of Site Closure

Although the Chemical Risk Assessment predicted negligible risk from non-radioactive hazardous substances, the information used for this assessment was incomplete and was based on numerous assumptions. For this reason, data from the Chemical Risk Assessment cannot be used independently to make closure decisions.

Early construction of a reliable, low-permeability cover over the chemical and mixed waste trenches will minimize the potential for future releases of non-radioactive hazardous constituents, and reduce future risk. The cover designs determined to have the best performance and reliability in Section 4.1.2.1 are the Enhanced Asphalt Cover, followed by the Enhanced Bentonite Cover, US Ecology Proposed Cover, and the Thick Homogenous Cover. The closure schedule alternatives that provide early coverage of the trenches containing non-radioactive hazardous chemicals are the Close-as-you-go Schedule and the US Ecology Proposed Schedule.

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[47] The infiltration rate used for the Chemical Risk Assessment was 68 mm/year compared to the Site Soils Cover of 20 mm/year.

[48] Risk to the onsite Native American Intruder is discussed because it was the most sensitive lifestyle.

Impacts of the Filled Site Alternative

There are no additional impacts from filling the site because there will be no more non-radioactive hazardous chemicals disposed at the commercial LLRW disposal site.

Mitigation Measures

Due to limited information available on significant adverse non-radioactive hazardous waste impacts, immediate placement of a low-permeability cover over the trenches containing non-radioactive hazardous waste is recommended to minimize infiltration.

Significant Unavoidable Adverse Impacts

None identified.

4.2 Affected Environment

This section discusses the existing environment and predicted future environmental impacts from License Renewal, NARM Acceptance, and Site Closure. Impacts are discussed for both the natural and built environment, including the earth, water, air, ecology, cultural resources, land use, catastrophic events, and socioeconomics.

Much of the natural environment has been impacted by past activities at the commercial LLRW disposal site. Two sets of environmental monitoring data are used in this DEIS to describe the current state of the natural environment. The first set is from the annual environmental monitoring program required in the US Ecology License. Monitoring under this program has been performed since 1965, and is designed to ensure compliance with license requirements and give early warning of any potential trends. All data tabulated in this section is referenced to the 1998 environmental monitoring data unless stated otherwise (US Ecology 1999).

The second set of data used to describe the existing environment at the commercial LLRW disposal site is from Phase 1 and Phase 2 of the US Ecology Site Investigation described in Section 2.5. The US Ecology Site Investigation provides limited data on the vadose zone and groundwater for both non-radioactive and radioactive constituents (Ecology 2000 and WDOH 2000).

4.2.1 Earth

The affected environment discussed in this section includes the climate, geology, and surface soils. The earth resources strongly influence how the commercial LLRW disposal site will impact the environment. A dry, arid climate, such as the climate at Hanford, is less conducive to significant environmental impacts. The same can be said about the thick basalt rock underlying the site. Surface soils can also influence the degree of contamination at the commercial disposal site. The sandy surface soils at the commercial disposal site have higher infiltration rates that can contribute to groundwater contamination. An even higher infiltration rate is possible if the sandy soils are disturbed, further reducing their water holding capacity and amount of vegetative cover.

4.2.1.1 Climate

Climate at the Hanford Site is strongly influenced by the rain shadow effect of the Cascade Mountain Range. Climatic data have been collected at the Hanford Meteorological Monitoring Network sites. The Hanford Meteorological Station (HMS), located near the commercial LLRW disposal site, is the most completely instrumented station. From 1961 through 1990, the average monthly temperatures varied from 30° Fahrenheit (F) in January to 76.2° F in July, with a yearly average of 53.2° F (Neitzel 1996). The average annual precipitation measured at the HMS is 6.6 inches. The bulk of the precipitation (54%) occurs November through February. Annual average snowfall is 15 inches (Neitzel 1996).

The Richland area is known for its windy conditions and its "dust storms." Prevailing winds are generally from the west-northwest, while peak gusts are from the southwest throughout the year. Wind speeds average four to seven miles per hour with the strongest winds occurring in June. Winds over 18 miles per hour occur less than five percent of the time. Atmospheric dispersion, or the ability for particles such as soil and contaminants to be carried by the wind, is highest in the summer and lowest in the winter (Neitzel 1996).

4.2.1.2 Geology

The commercial LLRW disposal site is characterized by thick basaltic lava flows overlain by unconsolidated sediments varying in thickness and texture. The "Hanford Formation" is about 250 feet thick beneath the commercial LLRW disposal site and consists of alternating layers of silt, fine sand, and medium to coarse sand over poorly sorted sands, silts, and gravels. Below the Hanford Formation is the "Middle Member of the Ringold Formation", consisting of silty, sandy gravel with well-rounded pebbles and small amounts of cementation (Neitzel 1996). Site-specific geologic information is available from trench excavations and monitoring well installations. (CH2M Hill 1996).

4.2.1.3 Surface Soils

The *Soil Survey: Hanford Project in Benton County, Washington* (Hajek 1966) describes the predominant surface soil types on the central plateau as Quincy sand (40%), Burbank loamy sand (39%), and Ephrata sandy loam (14%). These site soils have characteristically low water-holding capacity due to low organic matter and clay content. The surface soils at the commercial LLRW disposal site are about 10 to 20 feet deep and are primarily sandy loam and silty sands (US Ecology 1996).

Soils at the commercial LLRW disposal site have been subject to disturbance from normal waste disposal operations for the past 30 years. Soil disturbance commonly alters soil productivity, structure, and water-holding capacity. Alterations to a soil's water-holding capacity can increase the infiltration of water through the soil column and potentially increase the transport of contaminants to groundwater.

Radioactivity in surface soils is monitored on a regular basis. The results of the 1998 annual monitoring for surface soil radionuclide levels are shown in Table 22.

Table 22: 1998 Radionuclide Concentrations in Soil (pCi/g)

Radionuclide	1998 Data		Reporting Level	*Ambient Background
	Maximum	Average		
Gross Beta	21.6	18.10	35.0	20.1
Total Uranium	0.8	0.36	1.0	0.5
Plutonium 238	<0.01	<0.01	0.03	<0.01
Plutonium 239/240	<0.01	<0.01	0.03	<0.01
Cesium 137	0.12	0.03	0.25	<0.04
Cobalt 60	0.03	<0.01	0.30	<0.01
Europium 155	0.06	0.03	0.25	<0.02

*Ambient background is based on data collected at Station #1, located at the northeast corner of the site (near the US Ecology office). These data are subject to influence by activities at Hanford.

The 1998 data indicate none of the above parameters are above the US Ecology License reporting levels. Minor fluctuations in soil radionuclide levels, including levels reported for Co-60, Cs-137, and Eu-155, are attributable to offsite influences. These offsite influences include U.S. DOE activities elsewhere on Hanford, and worldwide fall-out levels. The data indicate that current operations at the commercial LLRW disposal facility have not contributed significantly to surface soil contamination. In addition, historical environmental monitoring data indicate there are no apparent increasing trends of radionuclides in surface soils attributable to the commercial LLRW disposal site (Fordham 2000). There was no surface soil data provided by the US Ecology Site Investigation.

4.2.1.4 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

There are no known existing or predicted impacts to the climate or regional geology from waste management activities at the commercial LLRW disposal site. Impacts to surface soils can be reasonably expected from ongoing operations and closure of the commercial LLRW disposal site. Potential impacts include surface contamination, increased infiltration rates, destruction of soil microbiology, and loss of soil productivity.

Impacts of License Renewal

Relicensing is not expected to result in unacceptable surface soil contamination. As shown in Table 22, current radionuclide levels in soils are well below reportable levels in the US Ecology License. Future levels are expected to also be low, assuming future license requirements are comparable to current requirements.

Relicensing will result in continued soil disturbance at the commercial LLRW disposal site. If the site is operated until year 2056, approximately ten additional trenches will be excavated. Soil disturbance may increase water infiltration rates, potentially resulting in increased contaminant transport to the groundwater. Enhanced relicensing is not expected to increase or decrease soil disturbance in comparison to the pending action.

Impacts of NARM Acceptance

Based on past monitoring NARM is not expected to significantly increase surface soil contamination. Increased NARM volumes may require more trench capacity, resulting in greater soil disturbance.

Impacts of Site Closure

Site closure is not expected to increase soil disturbance except for a possible increase in temporary wind erosion. In fact, construction of a cover with silt loam soil will help mitigate soil disturbance by replenishing soil productivity, structure, and water-holding capacity, and isolating any soil surface contamination. Cover design alternatives with the most silt loam, such as the Enhanced Covers and Thick Homogenous Covers, will provide the best mitigation. Closure schedule alternatives that include early construction of a cover, such as the Close-as-you-go Schedule, will provide the earliest mitigation.

All cover designs except the Site Soils Cover require large quantities of silt loam soil for construction and may require development of a borrow site.[49]

Impacts of the Filled Site Alternative

The Filled Site Alternative will result in more soil disturbance, due to greater waste volumes. Increased soil disturbance may result in shorter contaminant travel times to groundwater.

Potential Mitigation Measures

- Select a final cover design with high silt loam content for closure.
- Immediately construct a low-permeability interim or final cover over filled trenches.
- Plant final cover with native plants.
- Use standard construction practices for closure to minimize erosion.

Significant Unavoidable Adverse Impacts

None identified.

4.2.2 Water

This section discusses the groundwater and surface water at or near the commercial LLRW disposal site. Generally speaking, the farther the groundwater and surface water are from an activity, the less impact that activity is likely to have on water quality. Of equal importance in determining impacts to water quality are the characteristics of the

[49] Another option is to purchase soil materials directly from a vendor.

“path” contaminants must travel to reach the groundwater or surface water. Soil and geological characteristics that slow the travel of water or the contaminants in the water result in fewer impacts to water quality.

For the discussion on groundwater, this section is divided into the vadose zone and the groundwater zone. In this DEIS, the vadose zone is defined as the sub-surface zone between the surface soils and the saturated zone. Groundwater is defined as the water in the saturated zone.

The groundwater under Hanford has been the subject of many investigations and reports over the past 50 years. Accurately assessing the current state of groundwater quality and future impacts has proven to be a challenge at Hanford. Although much groundwater data have been collected, knowledge of the resource is still incomplete.

4.2.2.1 Vadose Zone

The vadose zone averages 300 feet in depth under the commercial LLRW disposal site (US Ecology 1996). The rate of recharge through the vadose zone is estimated at less than 5 mm/year in undisturbed areas. Recharge in areas of disturbed surface soils has been estimated as high as 20 mm/year (Gee 1993).

Annual vadose zone monitoring for radionuclides at the commercial LLRW disposal site shows an increasing level of tritium and radon (Fordham 2000). Data from the US Ecology Site Investigation detected several nuclides in the vadose zone, including Am-241, Ni-63, Pu-238, Pu-239/240, Sr-90, and Tc-99 (WDOH 2000). In addition, both C-14 and Kr-85 were detected in soil gas samples (WDOH 2000). No environmental standards were exceeded, and the data indicate no risk to public health (and WDOH 2000).

The US Ecology Site Investigation also indicated the presence of non-radioactive hazardous substances in the vadose zone. Data indicate metals that exceeded the US Ecology Site Investigation screening levels include arsenic, beryllium, cadmium, and chromium. Semi-volatile organic chemicals detected include acetone, 1,2,4-trimethylbenzene, tetrachloroethane (PCE), toluene, and (total) xylene, but none exceeded the levels. Many volatile organic compounds were detected in soil gas samples. Similar to the data for radionuclides, the non-radioactive hazardous data show no environmental standards were exceeded and indicate no present risk to public health (Ecology 2000).

4.2.2.2 Groundwater

The groundwater beneath the commercial LLRW disposal site begins at approximately the 300-foot depth and is located in the upper part of the silty sands and gravels of the Middle Member of the Ringold Formation. Drilled wells surrounding the commercial LLRW disposal site indicate the direction of groundwater flow to be from southwest to northeast. The rate of groundwater flow in the unconfined aquifer is extremely variable. Groundwater flow under the commercial LLRW disposal site has been estimated at 1,095 ft/year (Grant 1996). This rate of flow was estimated using standard hydrogeologic techniques, but it has not been measured directly.

The confined aquifers, located below the unconfined aquifer, consist of sedimentary beds between basalt flows. In general, lateral groundwater flow in the confined aquifers appears to mirror the surface topography. The predominant flow direction of the confined basalt aquifers under Hanford is from west to east.

Table 23 reports the 1998 groundwater monitoring data for the commercial LLRW disposal site (US Ecology 1999). These data, when compared to historical annual monitoring data, show no increasing trend in groundwater concentrations attributed to the commercial LLRW disposal site. Increases in tritium and gross beta have been attributed to U.S. DOE activities elsewhere at Hanford (Fordham 2000).

Table 23: 1998 Groundwater Radionuclide and Nitrate Concentrations

Radionuclide	Levels in Downgradient Wells (pCi/L)		Levels in Upgradient Wells (pCi/L)		Reporting Level (pCi/L)
	Max	Min	Max	Min	
Gross Alpha	3.3	1.1	2.9	1.4	15.0
Gross Beta	8.8	4.6	14.6	5.6	50.0
Cobalt 60	< MDC	< MDC *	< MDC	< MDC	100.0
Cesium 137	< MDC	< MDC	< MDC	< MDC	200.0
Potassium 40	< MDC	< MDC	< MDC	< MDC	None
Nitrate	6.7 ppm	3.4 ppm	6.7 ppm	4.6 ppm	None
Plutonium 238	< MDC	< MDC	< MDC	< MDC	40.0
Plutonium 239/240	< MDC	< MDC	0.006	< MDC	40.0
Ruthenium 106	< MDC	< MDC	< MDC	< MDC	85.0
Total Uranium (U-234, 235, 238)	2.89	1.95	2.83	1.95	30.0
Carbon 14	< MDC	< MDC	< MDC	< MDC	2,000
Tritium	3444	2073	5062	975	20,000

*pCi/L means picocuries per liter
*MDC means minimum detectable level. Nuclide levels below the MDC cannot be measured precisely.

The US Ecology Site Investigation also provided data on groundwater below the commercial LLRW disposal site. No non-radioactive hazardous chemicals were detected in the groundwater. Gross alpha, gross beta, Co-60, Tritium, Tc-99, and Pu-239/240 were found above the detection limits. In general, the groundwater results from the US Ecology Site Investigation show that the concentrations for these radionuclides are higher in the upgradient wells indicating the source is, at least partly, from activities elsewhere on Hanford. It is not possible to determine from the data if the commercial LLRW disposal site is contributing to the groundwater concentrations. Further sampling will be conducted to further understand the impacts of the commercial LLRW disposal site on the environment (WDOH 2000).

As a measure of environmental impacts, the groundwater concentrations in Table 23 and the concentrations from the US Ecology Site Investigation can be compared to the State Groundwater Quality Standards (Chapter 173-200 WAC). Unlike the drinking water standards that were used to determine long-term public health risks from groundwater in Section 4.1.2.3.1, the groundwater standards are measured in the aquifer and can be used as an indicator of environmental impacts.[50] The groundwater quality standards for radionuclides are:

Radium 226	-	3 pCi/L
Radium 226/228	-	5 pCi/L
Gross Alpha	-	15 pCi/L
Gross Beta	-	50 pCi/L
Tritium	-	20,000 pCi/L
Strontium-90	-	8 pCi/L

None of the data show that a groundwater quality standard has been exceeded at the commercial LLRW disposal site.[51]

The Surface Water Quality Standards (Chapter 173-201 WAC) for radionuclides address many more radionuclides than the groundwater quality standards. The Columbia River, located approximately 17 miles east of the commercial LLRW disposal site, is the nearest perennial surface water body in the direction of groundwater flow (Neitzel 1996). There has been no documentation of contaminants reaching the Columbia River from the commercial LLRW disposal site. However, U.S. DOE has documented impacts on the Columbia River from their past activities elsewhere at Hanford (PNNL 1999).

4.2.2.3 Predicted Impacts to Groundwater

Five radionuclides are predicted to impact groundwater quality during the 10,000-year post-closure period (see Table 14) (Dunkelman 2000). They are chlorine 36, iodine 129, technetium 99, uranium 235, and uranium 238. The long-term public health impacts of these radionuclides in groundwater was discussed in Section 4.1.2.3.1. To determine environmental impacts, these radionuclides were compared to the groundwater standards. None of these five radionuclides have a corresponding state

[50] The Groundwater Standards are an indicator of environmental impacts but are also based on public health.
[51] Annual groundwater monitoring is not done for radium 226, radium 226/228, or strontium 90.

groundwater quality standard other than the screening standards of 15 pCi/L gross alpha and 50pCi/L gross beta. Table 24 lists the predicted gross alpha and gross beta levels for the cover design alternatives.

Table 24: Groundwater Concentrations for Gross Alpha and Gross Beta (through 10,000 years)

Cover Design Alternative	Closure Date	Gross Alpha Standard 15 pCi/L	Gross Beta Standard 50 pCi/L
Proposed US Ecology Cover	2056	0	180
Site Soils Cover	2000	0	220
Thick Homogenous Cover	2056	0	101
Enhanced Covers	2056	0	101
Enhanced Bentonite Cover	2000	0	95
Filled Site Alternative	2215	0	216

Gross alpha emitters predicted to reach groundwater are U-235 and U-238. Gross alpha is predicted to be 0 pCi/L for all cover designs during the 10,000-year post-closure period (Silverstone 2000).

All of the cover designs are predicted to result in gross beta levels exceeding the 50 pCi/L standard. The primary contributor to the gross beta is Tc-99. More than 90% of the total TC-99 has already been disposed at the commercial LLRW disposal site. This 90% of waste already disposed is the reason for only a 6-pCi/L difference between closure with the Enhanced Covers in the year 2056 and closure with the Enhanced Bentonite Cover in the year 2000. WDOH suspects the Tc-99 source term is greatly overestimated on past manifests and is planning to complete a review of Tc-99 source term by year 2001.[52] This review is expected to show that predicted gross beta levels would be below 50 pCi/L for most cover designs.

Contaminants from the commercial LLRW disposal site that leach into the groundwater may reach the Columbia River. Dispersion, attenuation, and groundwater flow patterns make it difficult to predict impacts to the Columbia River from the commercial LLRW disposal site. It is safe to say that predicted groundwater concentrations, attributable to the commercial LLRW disposal site that do reach the Columbia River, will be no greater than the groundwater concentrations predicted in Table 14.[53] The predicted future groundwater concentrations of chlorine 36, iodine 129, technetium 99, uranium 235, and uranium 238 are significantly less than the limits in the surface water quality standards. The one exception is gross beta that is predicted to exceed the 50 pCi/L standard in the groundwater.

[52] New source term estimates for technetium 99 were not derived in time for use in this DEIS. A supplemental report will be completed, documenting the updated technetium 99 source term.
[53] Groundwater concentrations entering the river may be greater due to sources other than the commercial LLRW disposal site.

4.2.2.4 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Although current groundwater quality has not been impacted from operations at the commercial LLRW disposal site, post-closure concentrations of gross beta are predicted to exceed the State Groundwater Quality Standards. However, relicensing will only contribute a minor increase (6%) to the post-closure gross beta levels.

Impacts of NARM Acceptance

NARM is predominately radium and does not leach to groundwater, but instead emanates upwards as a gas. Therefore, the impact of NARM is predicted to be negligible on water quality.

Impacts of Site Closure

None of the five radionuclides predicted to impact groundwater will individually exceed a state groundwater quality standard. The gross beta activity from these five nuclides will exceed the gross beta standard for all cover design alternatives. The lowest concentrations of gross beta are predicted with the Enhanced Alternatives. The closure schedule alternatives that provide early waste isolation, such as the Close-as-you-go Schedule and the US Ecology Proposed Schedule, will minimize infiltration rates during the operational period and may reduce the post-closure concentration of gross beta in groundwater.

Impacts of the Filled Site Alternative

If the site is filled to capacity, none of the five radionuclides predicted to impact groundwater will exceed a state groundwater quality standard. The Filled Site Alternative does result in an increase of gross beta of approximately 20% (216 pCi/L).

Mitigation Measures

- Resample for radionuclides detected in groundwater to determine contributions from the commercial LLRW disposal site.
- Expand annual environmental groundwater sampling to include nuclides detected in the US Ecology Site Investigation.
- Select a final cover design with high performance and high reliability.
- Select a Closure Schedule Alternative that provides early waste isolation.
- Immediately construct a low-permeability interim cover over all filled trenches.

Significant Unavoidable Adverse Impacts

Post-closure gross beta levels greater than the 50-pCi/L gross beta standard are predicted for all cover designs.

4.2.3 Air Quality

This section discusses current air quality, based on annual environmental monitoring performed at the commercial LLRW disposal site. This section also discusses the potential for fugitive dust emissions. Long-term health impacts, resulting from radon or other airborne radionuclides, are discussed in Section 4.1.2.

Existing air quality at and adjacent to the commercial LLRW radioactive waste site is generally good but has been influenced by fugitive dust and routine emissions of radionuclides from Hanford**.** Sources of regulated airborne emissions at Hanford have included combustion equipment (e.g., steam boilers, electric generation plants), chemical separation processes, storage tanks, waste handling, and waste disposal.

Airborne radioactivity at the commercial LLRW disposal site is monitored on a regular basis. Historic annual environmental monitoring data indicate there are no long-term increasing trends for airborne radionuclides attributable to the commercial LLRW disposal site. The 1998 environmental monitoring data shown in Table 25 appear to indicate an increase in radon. The apparent radon increase has historically been intermittent and concurrent with periods of surface soils excavation (Fordham 2000). The Maximum Exposed Individual (MEI) is a person assumed to be on the commercial LLRW disposal site and near the package inspection facility. Data show that the MEI is less than 0.1 mrem/year for the commercial LLRW disposal site which is significantly lower than the 10-mrem/year ambient air quality standard (Fordham 2000).

Table 25: 1998 Airborne Radionuclide Concentrations (uCi/cc)

	1998 Data			Reporting Level	Background Levels
Radionuclides (Inhalation)	**Maximum**	**Minimum**	**Average**		
Gross Beta	5.1 E-14	0.29 E-14	2.1 E-14	2.6 E-11	2.1 E-14
Gross Alpha	6.7 E-15	< MDC	2.0 E-15	1.7 E-14	1.8 E-15
Iodine 125	3.4 E-14	< MDC	1.4 E-14	2.3 E-10	1.4 E-14
Tritium	1.1 E-11	7.1 E-13	2.4 E-14	6.1 E-8	1.2 E-12
Radon-222 (pCi/L)	2.8	< MDC	1.4	None	1.3
Gamma Emitters	< MDC	< MDC	< MDC	5 x MDC	< MDC

- uCi/cc means microcuries per cubic centimeter
- MDC means minimum detectable concentration

4.2.3.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Relicensing the commercial LLRW disposal site will result in continued site disturbance and fugitive dust emissions through normal waste disposal activities. Dust control methods currently used at the commercial LLRW disposal site are expected to control fugitive dust at an acceptable level. The Enhanced License Renewal Alternative includes additional dust control requirements that are expected to reduce fugitive dust further. Based on past air monitoring, relicensing is not expected to have a significant impact on air quality.

Impacts of NARM Acceptance

All NARM disposed at the commercial LLRW disposal site is packaged before it arrives at the site. This packaging is expected to control any significant fugitive dust associated with current or increased volumes of NARM disposal.

Impacts of Site Closure

Cover design alternatives that minimize wind erosion will result in the lowest generation of fugitive dust. Cover characteristics that reduce wind erosion are surface gravel and soil types capable of sustaining vegetation. All cover designs, except the Site Soils Cover, are designed to minimize wind erosion, and therefore are expected to have a minimal impact on fugitive dust emissions.

Closure schedule alternatives that close the commercial LLRW disposal site in several phases will contribute to short-term increases of fugitive dust during each construction phase. The "No Early Construction" Alternative would have the least impact on fugitive dust because it has only one construction phase.

Impacts of the Filled Site Alternative

Operating the site for a significantly longer period will increase contributions to fugitive dust through soil disturbance associated with normal operations. Increased dust generation is not expected to be a significant environmental impact if current dust control measures are continued.

Mitigation Measures

Use enhanced dust control requirements if license is renewed.

Significant Unavoidable Adverse Impacts

None identified.

4.2.4 Ecology

This section discusses the flora and fauna at the commercial LLRW disposal site and the surrounding area. Hanford is a shrub-steppe ecosystem. Shrub-steppe is defined as a vegetative community consisting of one or more layers of perennial grass with a conspicuous but discontinuous over-story layer of shrubs. These communities usually contain big sagebrush (*Artemisia tridentata*) in association with bunchgrasses. Due to the past 50 years of restrictions, Hanford is now the largest tract of contiguous shrub-steppe habitat remaining in Washington State (Neitzel 1996)**.**

An ecological review of the 100-acre commercial LLRW disposal site was completed on October 10, 1997 (PNNL 1997). The commercial LLRW disposal site is located in the middle of shrub-steppe habitat, but only minimal vegetation is left within the developed portion of the site. The undeveloped section of the site (15 acres in the northwest corner) is mature shrub-steppe habitat. There is no aquatic habitat located within the 100 acres of the commercial LLRW disposal site.

Radionuclide levels in vegetation at the commercial LLRW disposal site are monitored regularly. Table 26 shows the 1998 annual monitoring data for vegetation:

Table 26: 1998 Radionuclide Concentrations in Vegetation (pCi/g)

	1998 Levels		Reporting Level	Ambient Background
Radionuclides	**Maximum**	**Minimum**		
Gross Beta (site)	53.0	7.8	100 (dry)	No background data available
Gross Beta (trench cap – deep rooted	40.9	20.3	100 (dry)	No background data available
Total Uranium (site)	0.04	0.005	0.25	No background data available
Total Uranium (cap)	0.11	0.06	0.25	No background data available
Plutonium 238 (trench cap + site)	< MDC	< MDC	0.02	No background data available
Plutonium 239/240 (trench cap + site)	< MDC	< MDC	0.02	No background data available
Cobalt 60 (trenches, site)	< MDC	< MDC	0.1	No background data available
Cesium 137	< MDC	< MDC	0.2	No background data available
Tritium (trench cap)	74.0	0.6	None	No background data available
Gamma Spec	< MDC	< MDC	5 x MDC	No background data available

*pCi/g means picocuries per gram
*MDC means minimum detectable concentration. Nuclide levels below the MDC cannot be measured accurately.

None of the 1998 data exceeded the US Ecology License reporting levels. While there appear to be seasonal fluctuations in the levels, annual and historical data do not indicate increasing nuclide levels in vegetation (Fordham 2000). Due to the offsite influences from activities elsewhere at Hanford, a background station for vegetation has not been designated (Fordham 2000).

4.2.4.1 Threatened and Endangered Species

No plants or mammals on the federal list of Endangered and Threatened Wildlife and Plants are known to occur on Hanford (Neitzel 1996). However, three species of birds are federally listed, and several species of plants and animals are under consideration for formal state listing. Two anadromous fish species are federally listed. They are the Upper Columbia River spring-run Chinook salmon (*Oncorhynchus tshawytscha*) and the Upper Columbia River steelhead (*Oncorhynchus mykiss*).

No federal or state listed threatened or endangered plant species occur in the central plateau (Neitzel 1996). Wildlife species of interest in the central plateau include the loggerhead shrike, sage sparrow, and burrowing owl (*Athene cunicularia*). Other bird species of concern that may occur in the shrub-steppe habitat of the central plateau are the long-billed curlew (*Numenius americanus*), ferruginous hawk (*Buteo regalis*), and Swainson's hawk (*Buteo swainsoni*). Reptile species of concern using the central plateau include the striped whipsnake (*Masticophis taeniatus*) and the desert night snake (*Hypsiglena torquata*) (PNL 1977).

No plant or animal species protected under the Endangered Species Act, candidates for such protection, or species listed by the state of Washington were observed in the vicinity of the commercial LLRW disposal site during the October 9, 1997 biological review (PNNL 1997). However, because the review was completed outside of the nesting season and the period of activity for reptiles, there may be animal species using the site that were not observed.

4.2.4.2 Ecological Risk

Ecological risk is one measure of impacts to ecological resources. A guidance value of 0.1 rad/day was used to assess the impacts of License Renewal, NARM Acceptance, and Site Closure on ecological risk[54] (Thatcher 2000a). WDOH evaluated a terrestrial ecosystem with a food web that includes grass, the Great Basin pocket mouse, the mule deer, a coyote, and a hawk. Table 27 lists the post-closure ecological risk for these species at the commercial LLRW disposal site.[55] The highest dose predicted was 0.05 rad/day for the mouse. None of the other organisms have doses that approach the guidance value of 0.1 rad/day. If there were no human intrusion into the waste after closure, the ecological dose would be essentially zeroed.

Table 27: Estimated Doses to Organisms in Terrestrial Food Web for the US Ecology Proposed Cover

Organism	Dose (rad/day)
Plant	2.3 E-05
Mouse	4.8 E-02
Mule deer	7.6 E-07
Coyote	1.4 E-03
Hawk	3.2 E-03

[54] Although there is no regulatory limit established for ecological radiological risk, the International Atomic Energy Agency has established a consensus standard of 0.1 rad/day as a level below which observable changes are not expected. A rad is defined as the radiation absorbed dose and is a measure of absorbed radiation.
[55] Ecological risk was calculated based on the US Ecology Proposed Cover and the US Ecology Closure Schedule. Risk for all other cover designs, except the Site Soils Cover, is expected to be equal to or lower than the risk calculated.

Ecological risk from hazardous substances was also evaluated in the Chemical Risk Assessment. Kirner estimated the ecological risk from hazardous substances was determined to be negligible (Kirner 1999).

4.2.4.3 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Relicensing the commercial LLRW disposal site is not expected to further disturb the shrub-steppe habitat onsite. However, relicensing will delay the return of the habitat that is already disturbed. Denying the US Ecology License will allow a quicker return of the disturbed habitat. The Enhanced License Renewal Alternative will not provide any additional protection of the shrub-steppe habitat.

Ecological risk is currently at extremely low levels on the commercial LLRW disposal site. Assuming that future site operations will be at least as protective of the environment as past operations, relicensing the site is not expected to significantly increase dose levels to the indicator species listed in Table 27.

Impacts of NARM Acceptance

NARM is not expected to add further impact to the ecological resources. Any additional new trench capacity needed for NARM will be located in the already disturbed area.

Impacts of Site Closure

All closure cover designs except the Site Soils Cover are expected to encourage the shrub-steppe habitat to eventually return and most likely thrive due to the silt loam soil in the covers. Planting a cover with native vegetation will also speed the recovery of the shrub-steppe habitat. Table 27 shows the predicted ecological risk associated with the US Ecology Proposed Cover as extremely low. It is assumed that all other covers, except the Site Soils Cover, will also result in an acceptable ecological risk.

The closure schedule alternatives that build a final cover early will allow quicker reestablishment of the shrub-steppe habitat. Earliest construction is provided through the Close-as-you-go Schedule, Proposed US Ecology Schedule, and the Prototype Schedule.

Impacts of the Filled Site Alternative

The Filled Site Alternative is not expected to result in a larger disturbed area at the commercial LLRW disposal site; however, it would significantly delay the reestablishment of the shrub-steppe habitat if the site were not closed until the year 2215. Ecological risk was not quantified for the Filled Site Alternative.

Mitigation Measures

- Protect undisturbed 15 acres in northwest corner of site during operations and closure.

- Select a final cover with high silt loam content to encourage re-growth of the shrub-steppe habitat.
- Select a closure schedule alternative that includes early construction of the final cover.
- Plant final cover with native plants.

Significant Unavoidable Adverse Impacts

The shrub-steppe habitat at the commercial LLRW disposal site has already been adversely impacted by past operations. License Renewal, NARM Acceptance, and Site Closure are not predicted to significantly further impact site habitat.

4.2.5 Cultural Resources

Cultural resources on federal land are protected under the National Historic Preservation Act of 1966 (36 CFR Part 61 Section 106). The National Historic Preservation Act protects historic or prehistoric objects, buildings, structures, or places used by humans that are recognized as important for an understanding of our state and national heritage.

The Hanford Cultural Resources Laboratory has recorded over 960 cultural resource sites and isolated finds (Neitzel 1996). Forty-eight archaeological sites and one building are included on the National Register. In 1983, a Mastodon bone was found in one of the trenches at the commercial LLRW disposal site. Further surveying of the trench showed no further findings (Carpenter 1983). In 1997, a cultural resource review of the commercial LLRW disposal site was conducted with a result of no significant finds (PNNL 1997).

The Natural Historic Preservation Act also protects tribal cultural resources. The tribal nations identify all of Hanford as a cultural property due to its spiritual, ancestral, and social importance (Harper 1998). Tribal nations have occupied parts of Hanford for at least 11,000 years. Hanford contains many sites of significant historical and spiritual importance to the Yakama, Umatilla, and Nez Perce peoples. Cultural identity is of fundamental importance to the tribes. Tribal cultural resources on Hanford include natural resources such as habitat, wildlife, soil, vegetation, and groundwater. Tribal cultural resources also include individual sacred sites and burial grounds. The identification of such properties is not dependent on physical evidence but on identification by the affected community. Essential to the tribal cultural identity is the ability for a tribal member to conduct tribal activities in a clean and whole environment.

4.2.5.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Relicensing the commercial LLRW disposal site will impact tribal cultural resources through continued disposal of waste. The Enhanced License Renewal Alternative will minimize impacts on tribal cultural resources by providing enhanced waste isolation. Denying the US Ecology License will have the least impact on tribal cultural resources because restoration of the site can begin sooner.

Impacts of NARM Acceptance

NARM is not expected to impact tribal use of the commercial LLRW disposal site for hunting, gathering, and other similar activities. However, the NARM contribution to indoor air radon will impact the use of sweat lodges by future onsite intruders. NARM's impact on sweat lodge use is dependent on NARM volumes and the cover design.

Impacts of Site Closure

Closing the commercial LLRW disposal site by leaving the waste in place will impact tribal cultural resources; however, the cover design alternatives will provide some mitigation. Cover designs that provide the best waste isolation, such as the Enhanced Covers, will provide the greatest protection to the natural environment, and hence the tribal cultural resources. Closure schedule alternatives, such as the Close-as-you-go and the US Ecology Proposed Schedule that begin early construction of the final cover, will help to minimize impacts on tribal cultural resources.

Impacts of the Filled Site Alternative

The Filled Site Alternative will bring more waste to the commercial LLRW disposal site, possibly keep the site operating longer, and leave more waste in place when closed. Of all the alternatives, the Filled Site Alternative will have the greatest impact on tribal cultural resources.

Suggested Mitigation Measures

- Protect undisturbed 15 acres in northwest corner of the site during operations and closure.
- Use enhanced practices for NARM disposal including a dedicated trench and deeper burial of NARM waste if site is relicensed.
- Select a final cover design with high performance and high reliability.
- Immediately construct a low-permeability interim cover over all filled trenches.
- Plant cover with native species.
- Continue consultation with tribal governments.
- Continue consultation with the State Historic Preservation Office.

Significant Unavoidable Adverse Impacts

License Renewal, NARM Acceptance, and Site Closure will all impact tribal cultural resources through continued waste disposal and leaving the waste in place after closure.

4.2.6 Land Use

This section addresses the land use of the Hanford central plateau. The debate on future land use at Hanford has been ongoing for many years. Current land use on the

Hanford Central Plateau is waste management and disposal. As the landowner, the U.S. DOE is responsible for determining future land use for the central plateau and elsewhere at Hanford. U.S. DOE has published two documents on their intentions for future use of Hanford titled *The Future for Hanford: Uses and Cleanup* (U.S. DOE 1992), and *Hanford Remedial Action Environmental Impact Statement and Comprehensive Land-Use Plan* (U.S. DOE 1999).

The 1992 report proposed, “In general, …the overall cleanup criteria for the central plateau should enable general usage of the land and groundwater for other than waste management activities in the horizon of 100 years from the decommissioning of waste management facilities and closure of waste disposal of waste disposal areas” (U.S. DOE 1992). At a subsequent date on November 2, 1999, U.S DOE adopted a record of decision for the Hanford Comprehensive Land Use Plan designating the central plateau, including the commercial LLRW disposal site, as a waste management zone. The Hanford Comprehensive Land Use Plan applies to the next fifty years (U.S. DOE 1999).

4.2.6.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal
No impacts to future land use are expected because relicensing the commercial LLRW disposal site is consistent with current U.S. DOE land use recommendations.

Impacts of NARM Acceptance
No impacts to future land use are expected because NARM disposal at the commercial LLRW disposal site is consistent with current U.S. DOE land use recommendations.

Impacts of Site Closure
Although covering the commercial LLRW disposal site and leaving the waste in place is consistent with current U.S. DOE land use plans, none of the cover designs or closure schedule alternatives will render the commercial LLRW disposal site suitable for general use 100 years after closure. The significance of the site not being suitable for the general public is not known because most of the central plateau will also be unsuitable for general use in the year 2156.

Impacts of the Filled Site Alternative
Filling the site and closing it in the year 2056 is consistent with current U.S. DOE land use recommendations. Filling the site by continuing site operations through year 2215 is inconsistent with U.S. DOE goals of eliminating waste disposal operations in the central plateau.

Mitigation Measures
Use enhanced post-closure institutional controls such as signage, monuments, and fencing and long-term surveillance to minimize improper land use of the commercial LLRW disposal site.

Significant Unavoidable Adverse Impacts
None identified.

4.2.7 Catastrophic Events

This section evaluates the potential of a catastrophic event based on past occurrences and regional statistics. Catastrophic events are natural or human-caused occurrences that are infrequent but have the potential to result in significant unavoidable adverse impacts. These events include extreme weather, volcanic activity, earthquakes, fire, and human-caused accidents. This section does not address every catastrophic event that could possibly happen. Events such as war, meteorites, and other extremely unlikely natural phenomena are not considered in this section.

4.2.7.1 Flooding

Cold Creek

Cold Creek is a small seasonal stream that flows through Hanford. It is the only potential offsite source of local flooding in the vicinity of the commercial LLRW disposal facility (Skaggs and Walters 1981). A hydraulic analysis conducted by Skaggs and Walters concluded that the commercial LLRW disposal site would not be impacted by a maximum peak discharge from Cold Creek.

Columbia River Flooding

There are three potential scenarios for a catastrophic flood on the Columbia River (US Ecology 1996). They are a maximum precipitation event, a breach of a nearby dam, or a landslide blockage of the Columbia River.

1. Maximum Precipitation and Runoff

The probable maximum flood for the Columbia River below Priest Rapids Dam was calculated to be 1,400,000 cubic feet per second (Neitzel 1996). A flood of this magnitude would inundate much of Hanford adjacent to the river, and large areas of the City of Richland. The central plateau, including the commercial LLRW disposal site, would remain unaffected by such a catastrophic flood.

2. Dam Failure

The U.S. Army Corps of Engineers studied the potential impact of a catastrophic flood from dam failure (U.S Army Corps of Engineers 1951). A hypothetical 50% breach of Grand Coulee Dam resulted in a calculated flow of 8,000,000 cubic feet per second. The areas inundated by such a flood would be more extensive than in the preceding analysis. The commercial LLRW disposal site would not be affected by this catastrophic flood event.

3. Landslide River Blockage

Several scenarios were evaluated for flooding due to landslides (Skaggs and Walters 1981). A one-million cubic yard landslide, together with a flood flow of 600,000 cubic feet per second (the 200-year flood), would result in a calculated flood wave crest elevation of 400 feet above mean sea level. A probable maximum flood flow of 1,400,000 cubic feet per second would result in a flood wave crest of 410 feet above mean seal level. In both cases, the US Ecology facility would not be affected.

Local Ponding Due to Severe Weather

In 1985, a sudden warm chinook weather system thawed the frozen ground and snow at the commercial LLRW disposal site, causing localized ponding. This was a short-term phenomenon lasting less than a week. There was no evidence of damage to the trenches, or any resulting contamination from this event (WDOH 1985). After this event, US Ecology constructed a storm drainage system to rapidly divert and move any standing water away from the trenches. This drainage system is designed to handle a 100-year, 24-hour storm event. The storm drainage system has worked well in subsequent events, and the likelihood of future flooding from a sudden thaw at the commercial LLRW disposal site is moderate to low.

4.2.7.2 Volcanoes

There are two volcanoes in proximity to the commercial LLRW disposal site. Mount Rainier is located about 125 miles from the Richland site. At 14,410 feet, it is the highest peak in the Cascade Range. This dormant volcano's size and mass of glaciers pose a variety of geologic hazards, both during dormant periods and inevitable future eruptions. Mount St. Helens is 130 miles from the disposal site. Although this volcano is much smaller than Mount Rainer, it is active and as recently as 1980 had a major eruption. Other than the devastation in the blast zone, the primary impact from the 1980 eruption was from ashfall. Significant impacts were felt within 50 miles of the commercial LLRW disposal site.

If Mount Rainier were to erupt, the only hazard predicted to affect the commercial LLRW disposal was volcanic ash (Hoblitt 1995). However, the 1980 eruption of Mount St. Helens shows that even thin accumulations of ash can profoundly disrupt activities. It was found that ashfalls of less than 1/4 inch were a major inconvenience, and that ashfalls of more than 2/3 inch brought most activities to a halt for several days. Ashfall on the site may impact traffic and operations.

4.2.7.3 Airplane Crash

Data maintained by the National Transportation Safety Board on airplane crashes in the Richland, Pasco, and Kennewick (Tri-Cities) area were reviewed for January 1983 through July 1998. During that 15-year period in the Tri-Cities, a total of 31 airplane crashes of all types resulted in a total of 12 fatalities (U.S. Department of Transportation 1998). There were no airplane crashes specifically identified for Hanford in the NTSB database.

Of the airplane crashes in the Tri-Cities area, 25 involved problems in take-off and landings and were confined to the near vicinity of an airport (within seven miles). Four crashes involved unsuccessful "crop dusting" encounters with "terrain conditions" and/or man-made objects, and three involved engine problems during flight. None of the three Tri-Cities accidents with engine problems involved commercial LLRW air carriers.

There are no airports within ten miles of the commercial LLRW disposal site, nor are there agricultural fields or "terrain conditions" in the vicinity. Based on this information, a potential airplane crash in the vicinity of the commercial LLRW disposal site would most likely be initiated by engine problems. Under such circumstances, the pilot would be seeking a flat, smooth area for a landing strip. Open disposal trenches would be avoided in favor of the apparently smooth surface of one of the completed trenches. Landing gear would likely sink into the soft sand or other cover material, and the aircraft would likely "nose over" or flip as has been documented on other engine failure crashes. Impacts to the commercial LLRW disposal site from the accident would likely be limited to repair of the trench cap.

4.2.7.4 Earthquake

Seismicity in the Columbia Plateau is attributed to a north-south compression force regime that has resulted in thrust or reverse dip-slip faulting. Recent seismic data and observations since 1872 show most large earthquakes occur further than 124 miles from the Pasco Basin. The 1996 National Earthquake Hazard Reduction Maps concluded that any area west of the crest of the Rocky Mountains is capable of experiencing a 7.0 magnitude earthquake. However, seismic events in the central Columbia Plateau, including the Pasco Basin, have generally been short in duration and less than 3.5 on the Richter Scale (Neitzel 1996).

The Hanford area is located in an area of moderate seismic activity (Department of Ecology 1987). The poor cohesive quality of the sand deposits in and around the site would make it unlikely that a fissure formed by seismic activity, however extreme, would remain open. The most serious potential seismic impact associated with the site would be the possibility that an earthquake could accelerate waste subsidence through mechanical agitation. This could lead to a rupture of containers or damage to the cover constructed for closure. Earthquakes intense enough to cause damage to the containers or an engineered cover have not been recorded at this site.

4.2.7.5 Fire

Range fires are not uncommon in the arid shrub-steppe environment. Range fires burn extremely hot on the surface but move fast enough to not cause much damage below the surface. A range fire burned approximately 200,000 acres on Hanford in August of 1984 (Price 1986). A range fire of this magnitude could easily destroy a trench cover's vegetation but would not be expected to damage the buried waste or a buried low-permeability barrier. Waste in open trenches would be subject to damage from a range fire, but it is expected to be minimal because most waste is enclosed in metal containers and is not combustible.

Table 28 summarizes the likelihood of a catastrophic event and possible outcomes.

Table 28: Summary of Potential Catastrophic Events

Catastrophic Event	Impacts	Probability
Flooding – Cold Creek	No impact to disposal site	Low
Columbia River Flood	No impact to disposal site	Low
Local Ponding	Standing water onsite may impact operations and closure	Low – Moderate
Volcanic Eruption	Ashfall resulting in temporary shutdown of operations.	Low – Moderate
Airplane crash	Damage to trench cover during operations or closure	Low
Earthquake	Increased subsidence may impact interim or final covers	Low-Moderate
Fire	Destroying cover vegetation may impact closure	Moderate

4.2.7.6 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of the pending actions are discussed for those catastrophic events that have a moderate or higher probability of occurring, as shown in Table 28. These are local ponding, volcanic eruptions, earthquakes, and fire.

Impacts of License Renewal

Renewing the US Ecology License at the commercial LLRW disposal site means that one or more trenches will be open at any one time. Local ponding due to extreme weather will have the greatest impact on open trenches. The current stormwater system has proven adequate during past storm events; however, the Enhanced License Renewal Alternative includes an enhanced stormwater system that should further reduce the risk of impacts from local ponding.

Volcanic ash is the primary impact expected from an eruption. No significant impacts are expected from ashfall if the US Ecology License is renewed. Earthquakes may accelerate subsidence in the trenches. The Enhanced License Renewal Alternative will decrease waste subsidence in the long-term by reducing voids between the waste packages.

Impacts of NARM Acceptance

No significant impacts from catastrophic events are expected from increasing or decreasing NARM volumes. The probability of a truck being stranded during volcanic activity is increased with higher NARM volumes, but a stranded truck is not considered a significant impact.

Impacts of Site Closure

Local ponding, if present, could cause a trench cover to exceed its water holding capacity, and increase infiltration. The Enhanced Cover Designs, with high water storage and a low-permeability barrier, will provide the best performance during a ponded water event.

Earthquakes may cause subsidence, resulting in damage to the final cover. For all cover design alternatives, subsidence and differential settlement are hard to predict. The Thick Homogenous Cover would sustain the least damage from subsidence because of its ability to “self-heal” cracks. The performance of the low-permeability barriers during differential settlement is unknown. Cover designs with more flexible barriers, such as bentonite or a synthetic layer, may sustain less damage.

The primary post-closure impact from a range fire is the destruction of cover vegetation. The cover designs such as the US Ecology Proposed Cover and Enhanced Covers that include a low-permeability barrier may perform best after a range fire. A low-permeability barrier would minimize infiltration during the time vegetation was lacking. The rate of vegetation growth after a fire will depend on the amount of silt loam in the cover, the extent of root damage from the fire, and the amount of precipitation during the next several growing seasons.

Closure schedule alternatives that begin cover construction in the near future will provide an opportunity to monitor cover performance before final closure of the site. This includes the US Ecology Proposed Schedule, Prototype Schedule, and the Close-as-you-go Schedule. The Perpetual Care and Maintenance (PC&M) Fund will be available to mitigate impacts during the post-closure institutional control period.

Impacts of the Filled Site Alternative

No increased impacts are expected from filling the site.

Suggested Mitigation Measures

- Select a final cover design that has higher reliability when impacted by subsidence.
- Select a final cover design with a low permeability barrier to minimize infiltration if cover vegetation is destroyed during a range fire.

Significant Unavoidable Adverse Impacts

None identified.

4.2.8 Socioeconomic Considerations

This section discusses the impacts of the commercial LLRW disposal site on the socioeconomics of Washington State, the local host community, and the business community. Socioeconomics is a combination of social and economic factors. It includes impacts on employment, revenues, taxes, and costs to communities.

Benefits to the Host Community

The commercial LLRW disposal site employs 24 people directly and indirectly in the local community. Although this number is small relative to employment levels at Hanford, employment at the commercial LLRW disposal site contributes to employment diversification in the local area.

Benton County benefits financially from the commercial LLRW disposal site through lease payments and disposal fees. Table 29 shows the fiscal benefits to the host community if the commercial LLRW disposal site were operated through the year 2215.

Table 29: Lifetime Fiscal Benefit to Host Community

Closure Date	Cubic Feet/Year of Waste	Lifetime Lease Payment to Benton County	Lifetime Benton County Portion of Surcharge	Lifetime HAEIF Portion of Surcharge
2000	100,000	0	0	0
2056	100,000	$ 3,105,000	$11,200,000	$25,200,000
2215	100,000	$11,921,000	$43,000,000	$96,750,000

The Department of Ecology currently collects a sublease payment of $56,048 per year from US Ecology.[56] By a 1991 agreement, the Department of Ecology gives $55,448 of this payment to Benton County. In addition to the lease payment, Benton County receives fee money. In accordance with RCW 43.200.230, effective January 1, 1993, the Department of Ecology imposed a fee of $6.50 for each cubic foot of waste accepted for disposal at the site. These monies are split between Benton County ($2.00 per cubic foot) and the Hanford Area Economic Investment Fund (HAEIF) ($4.50

[56] Current terms require the sublease payment to be adjusted every three years based on the Consumer Price Index.

per cubic foot). In 1997, the fee generated $205,343 for Benton County and $462,021 for HAEIF.

Benton County also imposes a property tax on US Ecology of $5,800 per year. The costs for all fees and payments are passed on to the generator in the form of disposal costs.

Benefits to the State of Washington

The Department of Ecology is responsible for providing landlord oversight, maintaining a site use permit system for users of the commercial LLRW disposal site, and providing staff for the Northwest Compact. These activities are funded by revenue generated through the issuance of waste disposal permits. At present, permits for waste disposal at the commercial LLRW disposal site generate approximately $300,000 in annual revenue.

WDOH is responsible for facility operations and closure. WDOH funds its program through a cubic foot surcharge known as the "surveillance fee." Currently the surveillance fee is $ 6.00 per cubic foot and generates approximately $500,000 annually. The revenue collected by WDOH also funds the U.S. DOT inspection requirements that are carried out by the Washington State Patrol.

The WUTC regulates the disposal fees charged by US Ecology. The WUTC audits the company's expenses, including overhead, linking costs with specific waste disposal activities, and developing disposal rates that equitably distribute costs among site users. The activities of the WUTC are funded by a fee equivalent to one percent (1.0%) of the rates charged by US Ecology. These monies are included in US Ecology's annual revenue requirement.

The Department of Ecology is authorized to collect funds for the closure and perpetual care and maintenance of the commercial LLRW disposal site. A surcharge of $1.75 per cubic foot of waste is charged and deposited in the Perpetual Care and Maintenance Fund. As of November 30, 1999, this fund totaled $29,500,000 and will be used to ensure institutional controls, monitoring, and maintenance of the site for at least 100 years after closure. The Department of Ecology is not currently assessing a fee for the Closure Fund, although they have the authority to do so. The Closure Fund has a balance of $27,900,000 and is currently earning over $100,000.00 a month (Department of Ecology 2000).

Benefits to the Business Community

A favorable business climate is important to a healthy economy in Washington. A primary benefit of having the disposal facility within the Northwest Compact is that fees associated with low-level radioactive waste can be maintained at a reasonable and fairly consistent level for generators. If the commercial LLRW disposal site were closed, the two other commercial LLRW disposal sites in the country could accept some of the

Northwest Compact's waste. Currently, the South Carolina site could take Washington's low-level radioactive waste, but future access to that site will be restricted in the year 2008. Recent amendments to the Envirocare license means that facility could now accept approximately 85-90% of the regional waste by volume (Garner 1999). However, Envirocare cannot accept certain types of Class A waste, and no Class B or C low-level radioactive wastes (Garner 1999). Dependence on either of these sites would mean less certainty in disposal capacity and greater disposal costs for most regional generators.

Another regional benefit from the commercial LLRW disposal site is the attraction of new or existing industry to the region. The HAEIF receives $4.50 of the $6.50 surcharge assessed on each cubic foot of waste received for disposal. These moneys are used to build and diversify the economy in the Tri-Cities. Since 1993, there has been an increase in the number of permits issued to Washington generators. However, it is difficult to directly correlate this increase in generators to the efforts of HAEIF or the availability of reasonably priced disposal capacity.

Costs to the State of Washington, Host Community, and Business Community

Primary socioeconomic costs are from impacts on the infrastructure. The most obvious impact is transportation. Two hundred and twenty seven truck shipments were received in 1999. Other costs to the host community include demands for services that may be associated with transportation accidents. There are no known disproportionate costs to the business community from the operation of the commercial LLRW disposal site.

4.2.8.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Renewing the US Ecology license means that approximately 24 persons will continue to be employed in connection with the commercial LLRW disposal site. Overall, these employment levels are small and would not have a measurable impact on the overall local economy. However, 25 jobs do contribute to the diversity of an economy strongly impacted by Hanford employment levels. Local government revenues from the commercial LLRW disposal site will also be affected by relicensing. Approximately $14 million in revenue to the county and $25 million in revenue to the Hanford Area Economic Investment Fund will not be realized if the US Ecology license is denied.

Relicensing will provide more funds for closure and perpetual care and maintenance. Earnings on the Closure Fund have ranged from 4% to 6% annually. Section 5.3.3.1 compares the Closure Fund with estimated closure costs. Estimating funds needed for perpetual care and maintenance is difficult to accurately predict. The only statement that can be made for certain is that the more funds available, the better assurance there exists that closure will be adequately funded and cared for.

Relicensing will also result in continued use of state roads for waste transport, which will result in some increased wear to those roads traveled.

If the US Ecology license is not renewed, there will be potential fiscal impacts to regional waste generators, as they will need to seek alternate disposal options. Complex rate structures at the other two commercial LLRW disposal sites make it difficult to predict exact impacts. In addition to the disposal charges at these other sites, Washington generators would be subject to higher transportation costs due to the increased trucking distances. Having reasonable disposal costs benefits both the individual businesses and the economic health of Washington State.

The Enhanced License Renewal Alternative may increase operating costs that, in turn, may increase disposal costs for generators. Increased operating costs for this alternative have not been calculated.

Impacts of NARM Acceptance

NARM volumes will affect the amount of revenue received by local government and deposited to the Perpetual Care and Maintenance Fund. Table 30 lists the annual revenue that would be received for NARM.

Table 30: Revenue Comparison for NARM

NARM ft^3/year	Benton County Annual Revenues	HAEIF Annual Revenues	Perpetual Care and Maintenance Fund Lifetime Contributions
8,600	$ 17,200	$ 38,700	$ 842,800
36,700	$ 73,400	$ 165,150	$ 3,600,000
100,000	$ 200,000	$ 450,000	$ 9,800,000

Accepting NARM at the commercial LLRW disposal site does not affect the capacity of the site for disposal of low-level radioactive waste. Disposal of 100,000 cubic feet per year of NARM plus 200,000 cubic feet per year of radioactive low-level waste will use only 60% of the total disposal capacity at the commercial LLRW disposal site.

Impacts of Site Closure

The cover design and closure schedule alternatives are not expected to significantly impact socioeconomics.

Impacts of Filled Site Alternative

The longer the site remains operating, the more revenue the local communities will receive. The Filled Site Alternative will provide approximately four times more revenue to the county. The Filled Site Alternative will also increase employment, or at least continue it for a longer period of time at the commercial LLRW disposal site.

Mitigation Measures

Provide job employment services for displaced workers if the US Ecology license is denied.

Significant Unavoidable Adverse Impacts

If the US Ecology license is denied, unavoidable impacts include loss of local revenue, loss of low-level waste disposal capacity for in-state and Northwest Compact generators, loss of local jobs, and loss of continued contributions to the Perpetual Care and Maintenance Fund.

4.2.9 Cumulative Effects

This section discusses the commercial LLRW disposal site's contribution to cumulative effects on the central plateau of Hanford during the 10,000-year post-closure period.[57] Cumulative effects are defined as the impact on the environment and public health when current impacts are added to past, present, and reasonably foreseeable future actions. Cumulative effects can be the result of individually minor but collectively significant actions taking place over a period of time (40 CFR 1508.7). There are no regulatory standards that directly address cumulative effects during the post-closure period. A guidance value of a 100-mrem/year dose from all U.S. DOE operations is established through U.S. DOE Order 5400.5.

Cumulative effects at Hanford are a serious concern because of the extent of past, current, and future waste management activities. These activities include the U.S. DOE operation and closure of the Environmental Restoration and Disposal Facility, management of K basins, remediation and closure of tank farms, replacement of the cross-transfer system, operation and closure of the U.S. DOE low-level radioactive waste burial grounds, and the operation and closure of the commercial LLRW disposal site (U.S. DOE 1996).

Cumulative effects from activities on the central plateau have been discussed in several documents, including the *U.S. DOE Hanford Remedial Action DEIS* and the *U.S. DOE Tank Waste Remediation System DEIS* (U.S. DOE 1996). In addition, U.S. DOE has attempted to quantify a cumulative radiological dose in the *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (PNNL 1998). The U.S. DOE Composite Analysis is a first step in evaluating cumulative radiological impacts on public health from disposal and closure activities. Each of the above documents include the commercial LLRW disposal site in their discussions, but none have provided a comprehensive, quantitative assessment of all cumulative impacts in or adjacent to the central plateau.

[57] This DEIS only discusses the contribution of the commercial LLRW disposal site to cumulative effects. It does not attempt to quantify cumulative effects from other sources. Quantifying other sources is beyond the scope of this DEIS.

The WDOH and the Department of Ecology recognize the U.S. DOE Composite Analysis as a first step in predicting a cumulative radiological dose from Hanford's central plateau. The cumulative dose of six mrem/year was predicted in the U.S. DOE Composite Analysis. Based on this figure, U.S. DOE estimates the cumulative radiological dose to be well within their goal of 30 mrem/year and significantly below the 100-mrem/year level. U.S. DOE also determined that the contribution from the commercial LLRW disposal site would be minimal within the 1,000-year post-closure period.

It is difficult to compare the cumulative dose predicted in the U.S. DOE Composite Analysis to the doses predicted by WDOH in the radiological risk assessment for the commercial LLRW disposal site.[58] There are several key differences between these two analyses. The first and most significant is that the U.S. DOE Composite Analysis considers only 1,000 years after closure, whereas WDOH's assessment considers 10,000 years. Secondly, the U.S. DOE Composite Analysis assumes the point of exposure to be the boundary of the waste exclusionary zone, as defined by the Hanford Future Site Uses Working Group in 1992. The WDOH Risk Assessment assumes a much closer point of exposure at the commercial LLRW disposal site's fenceline. Other differences between the two analyses include the hypothetical scenarios, source term estimates, and the computer models that were used.

4.2.9.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

The commercial LLRW disposal site will contribute to cumulative effects on public health, shrub-steppe habitat, water quality, air quality, local socioeconomics, and tribal cultural resources. The relative significance of these contributions is dependent on the sum contribution from U.S. DOE activities elsewhere at Hanford. The contribution of License Renewal, NARM Acceptance, and Site Closure to cumulative effects are expected to be relatively small in comparison to the contribution from elsewhere on Hanford. The one exception may be the gross beta concentration predicted in groundwater during the 10,000 year post-closure period.

The following discussion on the impacts from License Renewal, NARM Acceptance, and Site Closure addresses their contribution to the cumulative annual individual dose.

Impacts of License Renewal

The contribution from License Renewal to the cumulative dose will depend on the selected cover design and future NARM volumes. Outside the boundary of the commercial LLRW disposal site but within the U.S. DOE exclusionary zone, relicensing will contribute a maximum additional dose of 2 mrem/year. Within the commercial

[58] Doses predicted from the WDOH Radiological Risk Assessment are significantly higher than those predicted in the Composite Analysis.

LLRW disposal site boundary, relicensing is predicted to contribute a maximum additional dose of 70 mrem/year to the cumulative dose (see Section 4.1.2.3).

The relative significance of the contribution to the cumulative dose from License Renewal is difficult to evaluate because the U.S. DOE Composite Analysis did not assess the cumulative dose within the exclusionary area boundary.

Impacts of NARM Acceptance

NARM is not predicted to significantly contribute to the cumulative dose outside the boundary of the commercial LLRW disposal site, but it will contribute a substantial dose to the onsite intruder. A NARM volume of 100,000 ft^3/year will contribute the greatest to the cumulative dose and a volume of 8,600 ft^3/year will contribute the least. NARM is predicted to contribute a minimum of 81 mrem/year, to a maximum of 1,000 mrem/year, depending on NARM volume, cover design, and closure date. The contribution of NARM to the onsite intruder is discussed in Section 4.1.2.3.1.

Again, the relative impacts of NARM on the cumulative dose cannot be adequately evaluated because there is no comparable data from U.S. DOE activities elsewhere at Hanford.

Impacts of Site Closure

Closure of the commercial LLRW disposal site will result in a range of contributions to the cumulative dose, depending on cover design and closure date. The post-closure contribution predicted outside the commercial LLRW disposal site boundary but within the exclusionary zone ranges from 5 to 32 mrem/year. The onsite contribution ranges from 91 to 950 mrem/year. Site Closure will also contribute a substantial level of gross beta activity to the groundwater.

It is reasonable to speculate that the contribution from the 100-acre commercial LLRW disposal site will be small relative to the contribution from the 560-square mile Hanford Site. However, regardless of the U.S. DOE contribution, cumulative effects at Hanford will benefit from a lower contribution from the commercial LLRW disposal site.

Impacts of Filled Site Alternative

The Filled Site Alternative will contribute 23 mrem/year to the offsite individual dose, and 520 mrem/year to the onsite dose.

Mitigation Measures

Suggested mitigation measures for cumulative effects include all mitigation measures listed in the preceding sections on public health, ecological resources, water quality, air quality, socioeconomics, and cultural resources.

Significant Unavoidable Adverse Impacts

From a cumulative perspective, there are no <u>known</u> significant adverse impacts. The significance of the impact is not known because the cumulative dose from the U.S. DOE activities elsewhere at Hanford is not well defined at this time.

4.3 Other Considerations

This section addresses other considerations for evaluating the impacts of License Renewal, NARM Acceptance, and Site Closure of the commercial LLRW disposal site. Other considerations include environmental justice, the US Ecology Site Investigation, and the costs of closing the commercial LLRW disposal site.

4.3.1 Environmental Justice

The purpose of this section is to identify and address any adverse disparate impacts to the affected minority or low-income populations from the pending actions of License Renewal, NARM Acceptance, and Site Closure. Potential adverse impacts to the affected minority or low-income populations are compared to the potential adverse impacts to the larger community. Any disparity in impact is assessed for significance (US EPA 2000).

There is a total population of approximately 384,000 people within a 50-mile radius of the commercial disposal site. The minority population within this radius consists of approximately 95,000 persons or 25% of the total population. The minority population includes Hispanic (80%) and Native American (8%) persons. These populations live primarily to the southwest and northeast of the Hanford Reservation and within the city of Pasco, Washington (Neitzel et al. 1997). Within the 50-mile radius, the low-income community comprises approximately 42 percent of households. The low-income households are primarily located to the southwest and north of the Hanford reservation and within the City of Pasco (Neitzel et al. 1997).

There are no persons living on or within the commercial disposal site for several miles. The commercial disposal site and the surrounding area is located on land ceded by the tribes to the United States under treaties of 1855. In addition, some of the lands surrounding the commercial LLRW disposal site were designated a national monument this year.

4.3.1.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal, NARM Acceptance, and Site Closure on long-term public health are discussed in Section 4.1.2. These impacts were quantified for the rural resident and for the Native American lifestyle. For this EIS, environmental justice impacts are evaluated by comparing impacts between these two communities. The rural resident lifestyle was selected for the environmental justice analyses because it is assumed to be representative of a rural non-minority lifestyle that may exist within the

10,000 year post-closure period.[59] The Native American lifestyle was selected because it is assumed to be representative of a community sensitive to environmental changes, and because of the Native American interests in the ceded lands.

Impacts of License Renewal

As shown in Section 4.1.2.4, impacts of License Renewal on the Native American community are slightly higher than impacts to the rural resident. However, the increased level of risk from License Renewal on the Native American community is less than two times that of the rural resident community and is therefore not considered significant (US EPA 2000).

Impacts of NARM Acceptance

Impacts from NARM are primarily from indoor radon exposure to the onsite intruder. The rural resident was assumed to be subject to a higher level of indoor radon than the Native American community based on the assumption that the rural resident adult spends more time inside than the Native American. The increased risk from indoor radon exposure occurs during the post-closure period and is included in the following discussion on Site Closure.

Impacts of Site Closure

The Native American community is predicted to be subject to a higher post-closure risk of cancer than the rural resident community. The higher risk is a result of the differences in the two different hypothetical lifestyle scenarios. The Native Americans are assumed to spend more time outside, eat more food raised on the land, use sweat lodges and live on or nearby the commercial disposal site for over twice as long as the rural resident living on the same site.

Assuming closure with the US Ecology Proposed Cover, if a Native American lives adjacent to the closed commercial disposal site for 70 years, that individual will theoretically receive a 12 millirem per year dose, or theoretically have a .04 percent chance of contracting a fatal cancer due to exposure from the closed site. If the rural resident lives adjacent to the closed commercial disposal site for 30 years, that individual will theoretically receive an 8 millirem per year dose, or theoretically have a .01 percent of contracting a fatal cancer. If a Native American lives onsite for 70 years, that individual will theoretically receive a 280 millirem per year dose, or theoretically have a 1.0 percent chance of contracting a fatal cancer. The rural resident living onsite for 30 years will theoretically receive a 310 millirem per year dose, or theoretically have a 0.5 percent chance of contracting a fatal cancer.[60]

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[59] The actual demographics of any affected community following the 10,000 year post-closure period are uncertain.

[60] These risk values are based on risk predicted for the USE Proposed Cover in Tables 18a and 18b. Although the annual dose is higher for the rural resident adult, the lifetime risk is higher for the Native American due to the assumption of their longer residency time onsite.

Impacts from the Filled Site Alternative will have a similar difference in risk between the rural resident and the Native American communities.

Mitigation Measures

All mitigation measures listed in section 4.1.3.1 are applicable. These measures will reduce the overall risk to all exposed persons, but are not expected to decrease any difference in impacts between the rural resident and the Native American communities.

Significant Unavoidable Adverse Impacts

To determine the significance of disparity between adverse impacts predicted for the Native American community and those predicted for the rural resident, the statistical significance of the disparity at two or three standard deviations was considered. For the 10,000-year post-closure period, the risk estimates for both the rural resident and the Native American communities have high degrees of uncertainty (Thatcher 2000a). The minor difference in the central risk estimates for the two communities is overwhelmed by the total uncertainty of either estimate (Thatcher 2000b). Based on this high uncertainty, there would be no statistical difference for risk between the rural resident and the Native American communities (Thatcher 2000b). Therefore, no adverse disparate impacts have been identified.

4.3.2 US Ecology Site Investigation

US Ecology recently completed Phases 1 and 2 of a Site Investigation (see Section 2.5). The US Ecology Site Investigation data indicate releases and potential continued releases of hazardous substances (Department of Ecology 2000). The Department of Ecology will require US Ecology to complete a Phase 3 of the investigation to further characterize the migration of non-radioactive hazardous constituents and any associated risk to public health and the environment (Department of Ecology 2000). Timely coordination of a Phase 3 US Ecology Site Investigation with License Renewal, NARM Acceptance, and Site Closure is important for both WDOH and the Department of Ecology to ensure compliance with their respective regulations.

One outcome of the Phase 3 US Ecology Site Investigation may be that a RCRA compliant cover be required to close the commercial LLRW disposal site. Table 31 shows those cover designs that comply with the RCRA minimum technical requirements[61] (Heppner 1998).

[61] RCRA does allow an equivalency evaluation for cover designs that do not meet the prescriptive RCRA minimum technical requirements.

Table 31: RCRA Cover Design Compliance

Closure Cover Design	Meets RCRA Requirements?	Comments
US Ecology Proposed Cover	No	Includes 1 foot thick bentonite/soil low-permeability barrier – RCRA compliance requires 2-foot thick bentonite/soil low-permeability barrier
Site Soils Cover	No	High infiltration
Thick Homogenous Cover	No	Lacks a low-permeability barrier
Enhanced Asphalt Cover	Yes	Meets requirements
Enhanced Synthetic Cover	Yes	Meet requirements
Enhanced Bentonite Cover	No	Includes 1 foot thick bentonite/soil low-permeability barrier – RCRA compliance requires 2-foot bentonite/soil low-permeability barrier

Only the Enhanced Asphalt Cover and Enhanced Synthetic Cover meet RCRA requirements. However, both the US Ecology Proposed Cover and the Enhanced Bentonite Cover could be made RCRA compliant by increasing the thickness of the low-permeability bentonite barrier to two feet rather than the proposed thickness of one foot (Heppner 1998).

4.3.2.1 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Relicensing the commercial LLRW disposal site is not expected to impact Phase 3 of the US Ecology Site Investigation. Denying the US Ecology License could impede Phase 3 because closing the entire site immediately may make it difficult or impossible to drill more vadose zone wells. The Enhanced License Renewal Alternative is expected to have no impact on the Phase 3 US Ecology Site Investigation.

Impacts of NARM Acceptance

There are no impacts to the US Ecology Site Investigation expected from NARM.

Impacts of Site Closure

Both the cover design and construction schedule for closing the commercial LLRW disposal site could impact the Phase 3 US Ecology Site Investigation. Closure schedule alternatives that include early construction of the cover could potentially impact the ability to drill new wells or identify new sample points. All closure schedule alternatives, except the “No Early Construction” schedule, have the potential for this type of impact. The agencies are coordinating their activities and are committed to ensuring the Phase 3 US Ecology Site Investigation does not adversely impact the closure schedule.

Impacts of the Filled Site Alternative

No impacts to the US Ecology Site Investigation are expected from filling the site.

Mitigation Measures

- If the site is relicensed, cover with an interim (versus final) low-permeability cover that can be sampled through, modified, and removed and replaced if necessary to accommodate the Phase 3 of the US Ecology Site Investigation.

- If the site is relicensed, design Phase 3 of the US Ecology Site Investigation so it can be completed before any final covers are constructed or so it can be conducted concurrently with closure of the commercial LRW disposal site.

Significant Unavoidable Adverse Impacts

None identified.

4.3.3 Costs and Surety

Costs associated with License Renewal and NARM Acceptance are not addressed in this DEIS.[62] However, because closure is dependent on the availability of funds, this section does evaluate the costs of cover design and the closure schedule alternatives.[63] All costs and analyses shown in this section are referenced to *Evaluation of Cost and Surety Projections for DEIS Alternatives for the LLRW Site – Conceptual Design, and Timing and Phasing* (Blacklaw 1998a).

Cover design costs are summarized in Table 32. As a reference point, these costs are shown in 1998 dollars and assume that no construction of the cover before final closure. Costs are not included for the Site Soils Cover because costs for the Site Soils Cover are considered operational rather than closure costs. Cover design characteristics that increase costs the most are the low-permeability barrier and silt loam soil. The Enhanced Asphalt Cover is the most expensive because of the asphalt barrier, and the Thick Homogenous Cover is the least expensive because it does not include a low-permeability barrier. If the Site Soils Cover were included in this analysis, it would cost significantly less.

Table 32: 1998 Costs for Conceptual Cover Designs

Cover Design	US Ecology Proposed Cover	Thick Homogenous Cover	Enhanced Asphalt Cover	Enhanced Synthetic Cover	Enhanced Bentonite Cover
Close Entire Site in Year 2056	$33,582,000	$29,585,000	$55,650,000	$35,903,000	$38,143,000
Close Entire Site in Year 2000	$22,937,000	$20,207,000	$38,009,000	$24,522,000	$26,052,000

[62] The SEPA regulations do not require financial costs to be considered.
[63] These costs are specifically for construction of the cover and associated costs. These cost estimates do not include other closure costs such as surface decontamination and institutional controls.

In addition to the cover design costs, closure costs are affected by the date of closure and the closure schedule. Table 33 combines cover design costs with closure schedule alternatives. A "closure scheduling cost factor" shows the cost of the schedule alternatives relative to closing the entire site in year 2056. The higher this factor, the more expensive the closure schedule alternative. Scheduling costs vary according to the number of construction periods and the amount of waste disposed at closure.

Table 33: 1998 Cover Design Costs Versus Scheduling Alternatives

Closure Scheduling Alternatives and Filled Site Alternative	Cover Design					
	Closure Scheduling Cost Factor[64]	US Ecology Proposed Cover	Thick Homogen-ous Cover	Enhanced Asphalt Cover	Enhanced Synthetic Cover	Enhanced Bentonite Cover
Close Entire Site in Year 2000	0.68	$22,937,000	$20,207,000	$38,009,000	$24,522,000	$26,052,000
"No Early Construction Alternative"	1.000	$33,582,000	$29,585,000	$55,650,000	$35,903,000	$38,143,000
US Ecology Proposed Schedule Alternative	1.120	$37,612,000	$33,135,000	$62,328,000	$40,211,000	$42,720,000
Prototype Schedule Alternative	1.098	$36,873,000	$32,484,000	$61,104,000	$39,421,000	$41,881,000
Close-as-you-go Schedule Alternative	1.150	$38,619,000	34,023,000	$63,998,000	$41,288,000	$43,864,000
Filled Site Alternative	1.690	$56,720,000	$49,969,000	$93,993,000	60,640,000	$64,424,000

4.3.3.1 Surety Adequacy

"Surety" is a measure of whether or not the Closure Fund has or will have enough funds to cover the cost of closure. On November 30, 1999, the Closure Fund totaled $27,900,000. Closure costs are expected to escalate at the rate of inflation as reflected by the Consumer Price Index (CPI). For estimating surety, a conservative growth rate of 2% was used for the Closure Fund.[65] Table 34 shows the ratio between the projected value of the Closure Fund at the time of fund obligation and the cost of the cover design/schedule combination. When the ratio is less than 1.0, the cover design

[64] The closure scheduling cost factor represents the relative costs between the "No Early Closure" Alternative (factor = 1) and other closure schedule alternatives.
[65] Current growth of the Closure Fund actually ranges from 4% to 6%.

and closure schedule combination will exceed available closure funds.[66] When the ratio is 1.0 to 1.25, the surety of the closure fund is considered marginal.[67] When the ratio is greater than 1.25, the closure fund is adequate to fund the estimated cost of closure.

Table 34: Comparison of Surety Adequacy*

Closure schedule Alternatives and Closure Dates	Cover Designs				
	US Ecology Proposed Cover	**Thick Homogenous Cover**	**Enhanced Asphalt Cover**	**Enhanced Synthetic Cover**	**Enhanced Bentonite Cover**
Close Entire Site in 2056	2.5	2.8	1.5	2.3	2.2
Close Entire Site in 2000	1.2	1.4	0.7	1.1	1.1
US Ecology Proposed Schedule Alternative	1.5	1.7	0.9	1.4	1.3
Prototype Schedule Alternative	1.9	2.2	1.2	1.8	1.7
Close-as-you-go Schedule Alternative	1.2	1.3	0.7	1.1	1.0
Filled Site Alternative – Close Site in 2215	14.7	167.2	88.9	137.9	129.9

*No shading means adequate surety.
*Light shading means marginal surety.
*Dark shading means inadequate surety.

4.3.3.2 Summary of Impacts, Mitigation Measures, and Significant Unavoidable Adverse Impacts

Impacts of License Renewal

Relicensing affects closure costs because continued waste means a larger cover will be needed to close the site. Relicensing also affects the Closure Fund because the longer the site operates, the more opportunity for the Closure Fund to grow. If the US Ecology License is denied, only the Thick Homogenous Cover could meet the 1.25 margin-of-safety factor as shown in Table 34. Relicensing the site allows more cover design alternatives to be considered with the current Closure Fund.

[66] The Department of Ecology has the authority to reinstate a fee on generators to increase the Closure Fund.
[67] A margin of safety of less than 1.25 is considered unacceptable for a project of this magnitude.

Impacts of NARM Acceptance

NARM volumes are not expected to impact the cost of closure, although NARM could contribute to the Closure Fund if additional fees are imposed on generators. If Closure Fund fees are reinstated, 100,000 ft^3/year of NARM will contribute the greatest amount to the closure fund. NARM volumes will also contribute to the Perpetual Care & Maintenance Fund.

Impacts of Site Closure

The Thick Homogenous Cover is the most affordable cover design and meets the margin of safety factor for all closure schedule alternatives. The Enhanced Asphalt Cover is the most expensive cover design and meets the margin of safety factor only if the final cover is constructed entirely in the year 2056 (“No Early Construction” Alternative). The Close-as-you-go Schedule is the most expensive scheduling alternative and is marginal for all cover designs except the Thick Homogenous Cover. All closure design/schedule alternatives could be affordable if the Department of Ecology reinstated the Closure Fund fee to pay the anticipated cost of closure.

Impacts of Filled Site Alternative

The Filled Site Alternative is a more costly alternative, but the higher earnings on the closure fund compensate the higher costs.

Suggested Mitigation Measures

If the site is relicensed, WDOH will research design and construction cost saving opportunities for covers where surety is marginal or inadequate. Depending on the cover design and closure schedule alternative, the Department of Ecology may need to reinstate the generator fees to increase the Closure Fund.

Significant Unavoidable Adverse Impacts

Significant adverse cost impacts apply to certain covers in combination with certain closure schedule alternatives.

GLOSSARY OF TERMS

100-year flood. A flood event of a magnitude that occurs, on average, once every 100 years, and equates to a 1-percent probability of occurring in any given year.

Affected environment. In an environmental impact statement, a description of the existing environment, covering information that directly relates to the scope of the proposed action and alternatives that are analyzed in the impact analysis. The affected environment provides a baseline and must include sufficient detail to support the impact analysis, including cumulative impacts. Environmentally sensitive resources, such as floodplains and wetlands, threatened and endangered species, prime and unique agricultural lands, and historic and cultural resources, must be identified.

Background radiation. Radiation from cosmic sources; naturally occurring radioactive materials, including radon (except as a decay product of source or special nuclear material); consumer products containing nominal amounts of radioactive material or producing nominal amounts of radiation; and global fallout that exists in the environment (e.g., from the testing of nuclear explosive devices).

Confined aquifer. An aquifer bounded above and below by less permeable layers. Groundwater in the confined aquifer is under a pressure greater than atmospheric pressure.

Contamination. The presence of unwanted radioactive and/or hazardous materials above background concentrations in environmental media (e.g., air, soil, and water) or on the surfaces of structures, objects, or personnel.

Cumulative effect. The impact on the environment that results from the incremental impact of the action when added to other past, present, and reasonably foreseeable, future actions. Cumulative impacts can result from individually minor, but collectively significant actions taking place over a period of time.

Cultural resources. Areas or objects that are of cultural significance to human history at the national, state, or local level. Generally includes paleontological, pre-contact, and post-contact resources, as well as resources of traditional use or religious value to Native Americans.

Curie. A unit of activity defined as the quantity of any radioactive nuclide in which the number of disintegrations per second is 3.700×10^{10}.

Decommissioning. The process of removing a facility from operation, followed by decontamination, entombment, dismantlement, or conversion to another use.

Dose (or radiation dose). A generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent. Relates to a chemical to which an organism is exposed; generally denotes the quality of radiation or energy that is absorbed by the organism.

Endangered species. Animals, birds, fish, plants, or other living organisms threatened with extinction by man-made or natural changes in their environment. Requirements for declaring a species endangered are contained in the *Endangered Species Act of 1973*.

Environmental justice. The fair treatment of people of all races, cultures, and income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.

Fugitive dust. The particulate matter that is stirred up and released into the atmosphere during excavation or construction activities.

Groundwater. The supply of water in the saturated zone below the land surface.

Half-life. The time in which half the atoms of a particular radioactive substance disintegrate to a different nuclear form. Used as a measure of the persistence of radioactive materials; each radionuclide has a characteristic, constant half-life. Measured half-lives vary from millionths of a second, to billions of years.

Hanford Federal Facility Agreement and Consent Order. The *Hanford Federal Facility Agreement and Consent Order* (also referred to as the Tri-Party Agreement, or TPA), is a binding agreement, negotiated pursuant to Section 120 of the *Comprehensive Environmental Response, Compensation, and Liability Act of 1980*, and other regulations signed by the U.S. Department of Energy, the U.S. Environmental Protection Agency (Region 10), and the Washington State Department of Ecology, to organize responsibilities for remediation of the Hanford Site and to establish milestones by which the remediation will be accomplished. This agreement commits the three agencies to a long-term cooperative program to remediate the contaminated sites at Hanford. The Tri-Party Agreement contains a blueprint for remediation and uses enforceable milestones to keep the program on schedule.

Hazardous Substance. Any non-radioactive substance that, when released to the environment in an uncontrolled or unpermitted fashion, becomes subject to the reporting and possible response provisions of the *Clean Water Act of 1977* and the *Comprehensive Environmental Response, Compensation, and Liability Act of* 1980 or the cleanup provisions of the *State Dangerous Waste Regulations and Model Toxics Control Act Regulations*.

Hazardous waste. Those wastes that are identified as hazardous pursuant to RCRA (40 CFR 261).

High-level waste. The highly radioactive waste material that results from processing or reprocessing spent nuclear fuel, including liquid waste produced directly from reprocessing, and any solid waste derived from the liquid that contains a combination of transuranic and fission product nuclides in quantities that require permanent isolation. High-level waste may include other highly radioactive material that the U.S. Nuclear Regulatory Commission, consistent with existing law, determines by rule to require permanent isolation.

Impact. The effect, influence, alteration, or imprint of an action. Impacts may be beneficial or detrimental.

Inadvertent Intruder. An individual who unintentionally intrudes into the disposal site and occupies the site or comes into contact with the waste at any time after active institutional controls are removed.

Institutional control. Control of waste management facilities through human institutions. Institutional controls include such measures as access restrictions, deed restrictions, or restrictions on activities or site use.

Land use. A term used to indicate the utilization of any piece of land. The way in which land is being used is the land use.

Low-level radioactive waste. Radioactive waste that is not classified as high-level waste, transuranic waste, or spent nuclear fuel. Test specimens of fissionable material irradiated for research and development, and not for the production of power or plutonium, may be classified as low-level radioactive waste if the concentration of transuranic elements is less than 100 nanocuries per gram of waste.

Maximally exposed individual (MEI). A hypothetical person who lives near Hanford and, by virtue of location and living habits, could receive the highest possible radiation dose.

Maximum contaminant level (MCL). Under the *Safe Drinking Water Act of 1974*, the maximum permissible concentrations of specific constituents in drinking water delivered to any user of a public water system that serves 15 or more connections and 25 or more people. The standards take into account the feasibility and cost of attaining the standard. In this environmental impact statement, MCLs are referred to as *Drinking Water Standards*.

Millirem (mrem). One thousandth (10^{-3}) of a rem (see also, rem).

Mitigation. Those actions that avoid impacts altogether, minimize impacts, rectify impacts, reduce or eliminate impacts, or compensate for impacts.

Mixed waste. Waste containing both radioactive and hazardous substances as defined by the *Atomic Energy Act of 1954* and the *Resource Conservation and Recovery Act of 1976*, respectively.

Model Toxics Control Act (MTCA). Washington state's hazardous waste cleanup law (RCW 70.105D) was adopted in 1989. Implementing regulations are Chapter 173-340 WAC.

Naturally Occurring and Accelerator Produced Material. Any radioactive material of natural or accelerator origin; does not include byproduct, source, or special nuclear material.

Nuclide. A generic term referring to all known isotopes, both stable and unstable, of the chemical elements.

Offsite. Any place located outside of the commercial LLRW disposal site.

Onsite. Any place located within the commercial LLRW disposal site.

Permeability. The degree of ease with which water can pass through a rock or soil.

Plume. The cloud of a pollutant in air, surface water, or groundwater formed after the pollutant is released from a source.

Probable maximum flood. The largest flood for which there is any reasonable expectancy in a specific area. The probable maximum flood is normally several times larger than the largest flood of record.

Rad. The unit of absorbed dose of ionizing radiation. One rad is equal to an absorbed dose of 100 ergs/gram.

Radiation (ionizing radiation). Alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. In the context of this DEIS, radiation does not include non-ionizing radiation such as radiowaves, microwaves, or visible, infrared, or ultraviolet light.

Radioactivity. Disintegration of unstable atomic nuclei by the emission of radiation, with a definite half-life.

Recharge. Replenishment of water to an aquifer.

Rem. The dosage of ionizing radiation that will cause the same biological effect as 1 roentgen of x-ray or gamma ray exposure. Acronym for roentgen-equivalent man.

Remediation. The process of cleaning up a site where a release of a radioactive or hazardous substance has occurred.

Riparian habitat. A specialized form of wetland restricted to areas along, adjacent to, or contiguous with perennially flooded and intermittently flowing rivers and streams. Also, periodically flooded lake and reservoir shore areas.

Risk. Quantitative expression of possible loss that considers both the probability that a hazard causes harm, and the consequences of that event.

Saturated zone. A subsurface area in which all pores are filled with water under pressure equal to or greater than atmospheric pressure.

Scoping process. An early and open public participation process for determining the scope of issues to be addressed, and for identifying the significant issues related to a proposed action.

Shrub-steppe. Typically a treeless area covered by grasses and shrubs and having a semiarid climate. Precipitation is typically very slight, but sufficient to support the growth of sparse grass and other plants adapted to living in conditions where water is scarce. Washington State Department of Fish and Wildlife considers shrub-steppe a priority habitat.

Source term. A measure of the activity of radionuclides. For the commercial LLRW disposal site. the source term is the total activity of disposed waste.

State Environmental Policy Act (SEPA). The general policies and regulations intended to help everyone make a better environmental decision; found in Chapter 43.21C of the Revised Code of Washington (RCW).

Surface Soil. The upper 10-20 feet of soil comprising the A, B and C horizons.

Total Effective Dose Equivalent (TEDE). The sum of the deep dose equivalent and the committed dose equivalent to the organ or tissue receiving the highest dose.

Transuranic waste. Waste containing more than 100 nanocuries of alpha-emitting transuranic isotopes, which have half-lives greater than 20 years, per gram of waste, except for (1) high-level radioactive waste; (2) waste that the U.S. Department of Energy has determined, with concurrence of the Administrator of the U.S. Environmental Protection Agency, does not need the degree of isolation required by 40 CFR 191; or (3) waste that the U.S. NRC has approved for disposal on a case-by-case basis in accordance with 10 CFR 61.

Unconfined aquifer. An aquifer that has a water table or surface at atmospheric pressure. At Hanford, the unconfined aquifer is the uppermost aquifer and is the most susceptible to contamination from Hanford operations.

Unsaturated zone. The portion of a porous medium where the interconnecting interstices are only partially filled with fluid.

Vadose zone. The area between the land surface and the top of the water table. Saturated bodies, such as perched groundwater, may exist in the vadose zone. The vadose zone is also known as the zone of aeration and the unsaturated zone.

Waste management. The planning, coordination, and direction of functions related to the generation, handling, treatment, storage, transport, and disposal of waste, as well as associated surveillance and maintenance activities.

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APPENDIX I

Description of Site Operations at the Commercial Low-Level Radioactive Waste Disposal Site

Description of Site Operations

at the

Commercial Low-Level Radioactive Waste Disposal Site

Washington Department of Health

June 25, 2000

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Operational requirements at the commercial low-level (LLRW) disposal site are listed in the Washington State radioactive materials license, WN-I019-2, issued by WDOH to US Ecology, Inc. (US Ecology). Additional procedures are listed in the Commercial Low-Level Radioactive Waste Disposal Facility Standards Manual. The US Ecology license is updated regularly and reissued on a five-year cycle. The following describes the current operations at the commercial LLRW disposal site:

1.0 Waste Inspections

There are two types of waste inspections required for the commercial LLRW disposal site. They are point-of-origin Inspections and onsite Inspections.

1.1 Point-of-Origin Inspections

The Washington Department of Health (WDOH) began the point-of-origin Inspection Program in 1992. The goal of the program is to identify any deficiencies at generator facilities *prior* to waste being shipped for disposal. Identifying deficiencies before the waste is shipped will reduce subsequent packaging or waste form violations upon receipt at the commercial LLRW disposal site. WDOH achieves this goal through random inspections of generator facilities. Washington is currently the only state in the nation that conducts point-of-origin inspections. This program was used as a basis for developing a Model Inspection and Verification Program (DOE/LLW-185) that was developed as guidance for other states.

1.2 Onsite Inspections

WDOH has a full-time onsite inspector at the commercial LLRW disposal site. US Ecology is required by their license to inspect at least 33% of the containers on each shipment for physical integrity, marking and labeling requirements, and correlation with the shipment manifest. A waste form confirmation program is also in place at the facility. This program requires US Ecology to inspect a minimum of one shipment per week, or one shipment out of every ten, whichever is more frequent. Shipments that undergo this inspection are set aside and all packages are individually examined, using nondestructive testing. At least one of these packages is opened and/or punctured in the presence of a WDOH inspector to determine compliance with waste form requirements.

In addition to the inspections noted above, both US Ecology and WDOH inspect trucks entering the facility for compliance with U.S. Department of Transportation (US DOT) regulations. The US DOT requirements address such things as shipment and package radiation levels, physical integrity of containers, and proper paperwork.

2.0 Waste Handling and Disposal

2.1 Packaging

Packaging refers to the types of containers the waste must be placed in for transport and disposal. Packaging requirements have changed over the past 30 years. In the past, cardboard and wood packages were allowed. Typical packaging today includes 55-gallon metal drums and steel boxes. There are packaging requirements for both waste stability and waste isolation. (Unstable waste must be placed in approved packaging such as high integrity containers (HICs) or engineered concrete barriers (ECBs).) Packaging requirements for waste isolation focus on package integrity. Containers received for disposal at the facility cannot show significant deformation, degradation, or any signs that radiation has dispersed through the container.

2.2 Waste Forms

WDOH has specific requirements on the form in which waste must be in before it can be disposed. For example, liquid wastes must be stabilized, or solidified. Absorbed liquids are not allowed. Liquids treated by stabilization must be processed to eliminate all freestanding liquid. Liquid wastes must also be rendered non-corrosive. Solid material containing incidental liquids is allowed, provided that the dry material contains less than 0.1% volume percent of liquid within the package.

Other wastes subject to specific waste form requirements include all class B and C waste, radioactive consumer products, chelated wastes, biological wastes, and Class B tritium wastes. Void spaces within all classifications of waste must be reduced to the extent practicable. However, void spaces in Class A stable, Class B, or Class C waste may not exceed 15% of the total volume of the waste package, unless disposed of in a HIC.

3.0 Trench Design

The commercial LLRW site uses conventional shallow-land burial. In shallow-land burial, large, unlined trenches are used for waste disposal. The trench soils are the primary method for containing the radioactive waste. The trenches are designed for long-term isolation and minimum active maintenance after site closure.

The maximum dimensions allowed for any trench is 150 feet (46 meters) in width, 45 feet (14 meters) in depth, and 1000 feet (305 meters) in length. Soils excavated during trench construction are used for backfilling, surcharging, and construction of berms. A registered professional land surveyor documents the trench location, and a geologist performs a visual inspection of the trench walls, prior to waste emplacement.

4.0 Waste Emplacement and Backfilling

4.1 Emplacement

Waste placed in steel boxes is stacked in trenches in an orderly manner, while drums are placed in the trench more randomly. Waste must be emplaced in a manner that maintains the package integrity during emplacement, minimizes void spaces between packages, and permits the void spaces to be back filled with site soils. Certain wastes must be segregated. Class A unstable waste is segregated from other waste by placing it into separate trenches. Class C waste is required to be disposed of at least five meters below the surface. Waste with a surface radiation level greater than 10 R/hr must also be disposed at a minimum depth of five meters below natural grade. Waste containing chelates in excess of 0.1% by weight must be segregated from other waste by placing it into ECBs. Packages containing gases must be placed in a manner that maintains package integrity, and with a minimum of ten feet from other gas containers.

Waste can only be held in storage for a maximum of 90 days. Storage of waste is monitored so that exposures are maintained as low as reasonably achievable and the dose limits are not exceeded.

4.2 Backfilling

Backfilling between waste containers must be done frequently enough that the radiation level at the trench edge does not exceed five mrem/hr. If possible, backfilling is to be performed concurrent as the waste is placed in the trench. At a minimum, backfilling is required so that the maximum unburied depth of Class A unstable waste is approximately twice the maximum package dimension. At no time is the uncovered depth of waste allowed to exceed six feet.

For Class B and C waste and waste with specific package segregation requirements, backfilling is required so that each layer is covered prior to subsequent waste emplacement. More frequent backfilling may be performed to minimize radiation exposures.

5.0 Manifest Tracking and Record Keeping

Each shipment of LLRW and Naturally Occurring or Accelerator Produced Material (NARM) arriving at the commercial LLRW disposal site is required to have shipping documents properly completed by the shipper. Each generator using the commercial LLRW disposal site must also have a valid site use permit issued by the Washington State Department of Ecology prior to shipping any waste for disposal.

US Ecology's license requires that waste shipments arriving at the disposal facility be accompanied by a shipment manifest approved by the Washington State Department of Health, a Washington State Patrol vehicle inspection certificate, and a copy of a current indemnification certification. WDOH requires that each manifest contain a detailed physical and chemical description of the waste, including the identity and quantity of radionuclides. The shipper must certify that the material is properly classified, packaged, and labeled for transport and disposal.

The onsite inspector reviews all shipping papers prior to acceptance of the shipment for disposal. No shipment may be offloaded unless the inspector has stamped and initialed the paperwork. A copy of the manifest accompanies the load to the trench for offloading. During the disposal process, a US Ecology Radiation Control and Safety Technologist records which trench the load was placed in, depth of waste burial, three-dimensional location of Class B and C waste, and the date of disposal. Detailed reports on waste disposal are required monthly, annually, and whenever a trench is closed.

6.0 Interim Closure

As trenches are filled to within eight feet of natural grade, a minimum of eight feet of site soils and six inches of gravel are placed over the trench. The interim trench cover is not considered a low-permeability cover. Interim trench markers are installed at each end of the trench and are inscribed with total activity, trench number, dates of operation, the volume of waste in the trench, and the coordinates of the disposal unit. A registered professional land surveyor surveys the trench, and the record of the trench is maintained on a scaled engineering topographical map.

Each quarter, visual inspections and radiation surveys of completed disposal units are performed to determine the condition of trench caps, changes in radiation levels, general condition of the disposal facility, and status of security measures.

7.0 Stormwater Management

The commercial LLRW disposal site has a water management diversion channel designed to control surface water drainage. The channel was built in response to a 1985 storm, which resulted in run-on at the site, due to frozen ground conditions. The diversion channel is engineered to accommodate a 100-year storm event, including rain on frozen ground events. The diversion channel is designed to minimize surface erosion, prevent run-on onto trenches, and limit contamination resulting from run-on and run-off.

8.0 Institutional Controls

Institutional controls are used to secure and control the commercial LLRW disposal site. In addition to the security provided by the US Department of Energy Hanford Site, the commercial LLRW disposal site is surrounded with a continuous eight-foot high chain link fence that is topped with barbed wire. The entire fence is posted for radiation areas. The entrance gate to this area is under direct surveillance during working hours and is locked after working hours.

9.0 Environmental Monitoring

Beginning in 1965, soil, groundwater, and vegetation monitoring have been performed periodically. Air quality monitoring began in 1978. Ambient air and other experimental monitoring began in the mid-980s. In 1987, a comprehensive environmental monitoring plan was initiated. Today there are nine permanent environmental monitoring stations surrounding the commercial LLRW disposal site, and several other stations throughout the site. Table 1 lists monitoring requirements included in the US Ecology license. Reporting levels, established in the license for each of the monitoring requirements, are based on the protection of public health. US Ecology publishes an annual environmental report documenting results of the previous year's monitoring.

Table 1: US Ecology Environmental Monitoring Requirements

Media Sampled	Sample Sites	Sample Frequency	Constituents Sampled
Soil	All nine stations, plus the NE and NW corners	Quarterly	Gross beta, total uranium, isotopic plutonium, gamma emitters
Vadose Zone*	Three vadose zone wells	Quarterly at depths of 35 feet	Toluene, xylene, methane and combustible gases, radon-222, tritium.
Groundwater	Eight wells	Quarterly	Gross alpha, gross beta, tritium, C-14, Pu- 238, Pu-239/240, Co-60, Cs-137, gamma emitters, total uranium, total dissolved solids, total organic carbon, nitrates, temperature, specific conductance
Air Quality	Nine stations	Continuous, weekly, and monthly	Gross beta, gross alpha, I-125, tritium, and gamma spectroscopy, Co-60, Cs-137
Ambient Air	Perimeter of site, and near active trenches	Quarterly and monthly	Penetrating radiation
Vegetation	Nine stations, NE and NW corner, and trench covers	Quarterly when available	Gross beta activity, total uranium, isotopic plutonium (Pu-238 and Pu-239/240), gamma emitters, and tritium.

10.0 Personnel Training

The commercial LLRW disposal site has a formalized written training program developed by US Ecology and approved by WDOH. The training program is reviewed and updated at least every two years. The program includes specific hours of classroom study, on-the-job training, and testing requirements for radiological workers, management, and unescorted visitors.

11.0 Emergency Response

US Ecology's *Radiological Contingency Plan* (RCP) outlines the actions to be taken if there is a significant release of radioactive materials to the environment at the commercial LLRW disposal site. The RCP contains detailed procedures for notification and response in case of a radiation emergency. A radiation emergency is defined as:

- fire
- major release of radioactive materials to the air, soil, or ground water
- transportation accident
- any event requiring evacuation
- any other hazardous materials event involving radioactive materials

To ensure readiness in case of an emergency, US Ecology performs periodic emergency drills at the commercial LLRW disposal site. The drills are unannounced and number at least three drills a year. The drills cover areas such as fire, release of radioactive material, and care of a contaminated injured person.

APPENDIX II

Radiological Risk Assessment
Low-Level Radioactive Waste Disposal Site
Richland, Washington

Washington State Department of Health
Division of Radiation Protection

RADIOLOGICAL RISK ASSESSMENT

LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE
RICHLAND, WASHINGTON

Andrew H. Thatcher, WDOH
with Ecological Risk by
Lissa Staven, PNNL

July 14, 2000

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1.0 INTRODUCTION

This report contains the analyses and results for estimating long-term health and ecological impacts from closing the commercial low-level radioactive waste disposal site (LLRW disposal site) in Richland, Washington. The report supports the Environmental Impact Statement (EIS) being prepared by the Washington State Departments of Health and Ecology. This report addresses long-term risk from the radiological waste disposed at the site from 1965 through the projected closure date. The objective of this report is to compare the relative long-term risk of the proposed closure plan to the alternatives to that plan (referred to collectively as the "alternatives"). For each alternative, the following analyses have been performed:

- Yearly dose estimates for the post-closure exposure scenarios
- Incremental lifetime cancer risks based on post-closure scenarios
- Predicted impacts to individuals as a result of inadvertent human intrusion
- Risk to ecological receptors

Section 2 briefly reviews the proposed closure plan and the alternatives. Section 3 presents the five exposure scenarios used for the risk calculations. Included in this section is a review of how the scenarios used in this analysis compare to the WDOH Hanford Guidance for Radiological Cleanup, the Hanford Site Risk Assessment Methodology (HSRAM), and the State Model Toxics Control Act (MTCA). Section 4 provides a review of the methodology used to calculate the risk. Subsections within Section 4 provide a discussion of the source term and the radiological risk analysis for both the offsite resident and the onsite intruder. Section 5 presents the risk results of the proposed alternatives for the four areas of analysis described in Section 3. Section 6 discusses the risk of the proposed alternatives to the intruder. Section 7 presents dose and risk results, using MTCA scenarios. Section 8 presents the ecological risk assessment methodology and results. Section 9 contains the analysis of the anticipated risk of varying the volume of Naturally Occurring or Accelerator Produced Radioactive Material (NARM) waste disposed per year. Section 10 presents an uncertainty analysis of the results presented in Sections 5 and 6. Finally, Section 11 contains a summary of the results.

2.0 PROPOSED ALTERNATIVES

The alternatives for the closure of the LLRW disposal site each include a cover over the site. The alternatives were designed to represent a reasonable range of cover designs and closure times. The primary difference is in their ability to stop the infiltration of water to the contaminated waste. Table 1 provides a brief synopsis of the different alternatives.

2.1 Description of Alternatives

Table 1 Description of Alternatives

Alternative Description	Final Close Date	Cover Description	Cover Infiltration through Top Layers
Proposed Action	Year 2056	Multi-layer cover with 4-inch 50% gravel surface layer, 36-inch silt loam and sand/bentonite infiltration barrier. Site soil layers added for total cover depth of 16' 4".	2 mm/yr
Filled Site	Year 2056 or 2215	Same as Proposed Action but assumes the site is filled to capacity through accepting higher annual volumes or extending the closure date.	2 mm/yr
Site Soils	Year 2000	Single layer cover of 11 feet of site soils.	20 mm/yr
Thick Homogeneous Cover	Year 2056	Three layer cover with 60-inch silt loam layer. Site soil layer added for total cover depth of 16' 6". No drainage barrier.	0.5 mm/yr
<u>Enhanced Designs:</u> **Design A – Asphalt layer** **Design B – Synthetic layer** **Design C – Sand/bentonite layer**	Year 2056	Three cover designs – all have 60 inches of site soil but with different drainage barrier. Each cover has site soil layers added for total cover depth of 16' 6".	0.5 mm/yr
Enhanced Bentonite - Year 2000	Year 2000	Uses Enhanced Bentonite cover (sand/bentonite layer), but site is closed in year 2000.	0.5 mm/yr

3.0 EXPOSURE SCENARIOS

In order to determine the risk that an individual would be expected to receive from the closure alternatives, scenarios are developed to approximate the lifestyles of the hypothetical individuals. The scenarios used for evaluation of the potential impacts from the LLRW disposal site are:

Offsite Rural Resident Scenario

Offsite Native American Scenario

Intruder Rural Resident Scenario

Intruder Native American Scenario

Intruder Construction Scenario

The basis for the general population scenarios can be found by reviewing the environmental impact statements supporting 10 CFR 61 [U.S. NRC, 1981, 1982], as well as the Hanford Site Risk Assessment (HSRAM) manual [U.S. DOE, 1995] and the WDOH Hanford Guidance for Radiological Cleanup [WDOH, 1997]. A comparison of the parameters defined for this analysis, the HSRAM manual, and the state of Washington Model Toxics Control Act (WAC 173-340) is provided. The Native American Subsistence scenario was modified from the CRCIA document [U.S. DOE, 1998] and the Tank Waste Remediation System FEIS [U.S. DOE, 1996], following consultation with representatives of the Confederated Tribes of the Umatilla Indian Reservation, the Yakama Indian Nation, and the Nez Perce Tribe.

3.0.1 Potential Impacts to a Child

Included in the rural resident scenario and Native American scenario is an analysis of the potential impacts to a child. The child scenario is developed using the same exposure pathways as the adult, but utilizes different intake parameters. The consumption information for the children is based upon data from the 1977-1978 Nationwide Food Consumption Survey conducted by the U.S. Department of Agriculture [Callaway, 1992]. The mean value is used as the basis for the consumption rates for nine different food categories.

The incremental lifetime cancer risk for the child is based upon a composite analysis that is evaluated using child parameters for six (6) years, and adult parameters for 24 years. For the six years as a child, the parameters correspond to the average consumption patterns of the 1-4 and 5-9 age groups.

3.0.2 Timing of Scenarios

Upon cessation of activities at the LLRW disposal site, the facility begins a multi-year final closure on those trenches not previously closed. A period of active monitoring begins immediately after final closure activities are complete. This "institutional control" period could last for several centuries,[1] but for this analysis, the active monitoring period is assumed to last only 107[2] years. During the institutional control period, lapses in land records that would result in inadvertent land purchase and squatting are presumed to not occur. As a result, intruder analysis predicting the impact to individuals of the general population or critical populations does not begin until 107 years following final closure.

It is conceivable for an individual to reside at the LLRW disposal site boundary prior to the end of institutional control.[3] In this event, exposure via a groundwater well or diffusion of radioactive gases could result in an impact during the 107-year institutional control period. In the methodology discussion, the impact of those exposures is included in the H-3, C-14, and Ra-226 discussions.

The following sections provide a description of the scenario, an outline of the pathways analyzed, and tables that indicate the parameters used in the analysis.

3.1 The Adult and Child Rural Resident Scenario: Offsite General Population

The rural resident is an individual living in a remote or sparsely populated area. The individual spends all of his/her time on his/her parcel of land. In order to maximize exposure, the individual resides at the LLRW disposal site boundary in a location that is the predominant downwind and downstream direction. The individual builds a house, drills a well, and raises crops and animals in order to support his/her rural lifestyle. Due to the limitations of the quantity produced and variety of fruits and vegetables, only a portion of the produce is grown on his/her land. Due to the use of the groundwater well, the individual is exposed to a number of pathways. The pathways analyzed for the rural resident scenario are [Kennedy and Strenge, 1992][4]:

- External exposure to radiation from contaminated soil while outdoors
- External exposure to radiation from contaminated soil while indoors
- Inhalation exposure to resuspended soil while outdoors
- Inhalation exposure to resuspended soil while indoors
- Inhalation exposure to resuspended surface sources of soil tracked indoors
- Inhalation exposure to gaseous radionuclides while indoors and outdoors
- Direct ingestion of soil

[1] A fund is currently held by the state that has sufficient funds to ensure that active monitoring and maintenance activities can continue well into the future.
[2] 107 years represents 100 years of institutional controls and seven years of onsite "active" maintenance.
[3] The disposal site remains located within the proposed active control area of the 200 Area [Kincaid, et al, 1998]. This active U.S. DOE institutional control would also have to lapse for an individual to reside at the boundary of the disposal site.
[4] Additional pathways that are considered but not analyzed are included in the methodology discussion. Examples are dermal absorption, and inhalation of groundwater contaminants while showering.

- Inadvertent ingestion of soil tracked indoors
- Ingestion of drinking water from a groundwater well (including while showering)
- Ingestion of plant products grown in contaminated soil
- Ingestion of plant products irrigated with contaminated groundwater
- Ingestion of animal products grown onsite

The offsite analysis assumes that exposures can only result from contaminated groundwater and/or aerial deposition from resuspended contaminated particles driven offsite. Inhalation of gases such as radon can occur through atmospheric dispersion. In the analysis, potential impacts such as resuspension from onsite are assumed to occur as a result of an onsite intruder. Table 2 provides an overview of the exposure pathways for the rural resident.

Table 2 Offsite Rural Resident Exposure Pathways

Exposure Pathways	Radionuclides
External exposure from gamma emitting radionuclides in soil while outdoors	Yes
External exposure from gamma emitting radionuclides in soil while indoors	Yes
Inhalation of resuspended soil and dust	Yes
Inhalation of radon and radon decay products from soil containing radium	Yes
Incidental ingestion of soil	Yes
Ingestion of drinking water transported from soil to potable groundwater sources	Yes
Ingestion of water containing contaminants during showering	Yes
Indoor inhalation	Rn-222 Only
Dermal absorption of contaminants via skin or puncture wounds	Tritium Only
Ingestion of home grown produce (fruits and vegetables)	Yes
Ingestion of meat containing contamination taken up by cows grazing on contaminated plants	Yes
Ingestion of milk containing contamination taken up by cows grazing on contaminated plants	Yes
Ingestion of meat and eggs containing contamination taken up by poultry feeding on contaminated produce	Yes
Ingestion of locally caught fish	No
Ingestion of organ meats, upland birds, waterfowl, wild bird eggs	No
Ingestion of game meat containing radionuclides	No

Table 2 compares the exposure parameters for the rural resident to the Agricultural scenario in HSRAM, the rural resident scenario in the WDOH guidance document and the available guidance found in MTCA. This comparison is conducted because HSRAM and MTCA are recognized as the governing cleanup approaches at the Hanford Reservation. The WDOH Guidance is referenced extensively in cleanup actions. Significant differences between the rural resident scenario for this EIS and the guidance for HSRAM, WDOH Guidance, and MTCA are:

- Soil ingestion rates – HSRAM and WDOH Guidance recommends 100 mg/d for the adult; MTCA recommends 50 mg/d. This report uses 50 mg/d. The 50 mg/d is further supported in the extensive soil ingestion review performed by S.L. Simon [Simon, S.L., 1998].

- HSRAM considers dermal exposure and absorption. This analysis considers dermal exposure and absorption only for tritium (Dermal absorption is discussed in greater detail in Section 4.3.4) as the absorption fraction for most radionuclides is quite small and not a large contributor to dose. WDOH Guidance does not consider dermal absorption.

- HSRAM considers groundwater and surface water inhalation, WDOH Guidance does not. Surface water inhalation is not considered for this analysis as the LLRW disposal site is not near a surface water source. Groundwater inhalation is considered for the Native American sweat lodge scenario. Groundwater inhalation while showering is briefly analyzed in Section 4.2.3 and is determined to not be a significant contributor to dose.

- Sediment ingestion is not considered in this analysis as no surface water source exists in close proximity.

- The EIS rural resident scenario does consider the ingestion of meat, poultry, eggs, and dairy products that are not considered in MTCA or HSRAM. WDOH Guidance considers the ingestion of meat, poultry and dairy products, but does not consider egg ingestion. The ingestion values for the EIS rural resident scenario are similar to those found in the WDOH Guidance. The EIS is more conservative than the WDOH Guidance in the ingestion of beef.

- The rural resident scenario does not consider the ingestion of fish and game meat. Fish ingestion is omitted because no source of surface water exists in close proximity to the LLRW disposal site. Game meat is not considered because the only source for contaminant uptake is via groundwater related activities. Farm animals are therefore viewed as always having a greater potential for exposure than game.

- This Radiological Assessment utilizes slightly lower produce ingestion rates as compared to HSRAM or WDOH Guidance. The differences are due to the use of NUREG 5512 as the primary reference for the analysis. The differences are well within the uncertainty of the produce intake rates for adults.

Table 3 Exposure Parameters Comparison for the Rural Resident

			Rural Resident Scenario	Hanford Guidance[5]	HSRAM	MTCA[6]
Media/Pathway		Exposure Parameters	Exposure/Intake/Contact Rate			
Soil	Ingestion	Soil ingestion rate (mg/d) (child)	200	NA	200	200
		(adult)	50	100	100	50
		Exposure frequency (days/year)	365	365	365	ND
		Exposure duration (years) (child)*	6 yr child, 24 yr adult[7]	NA	6	6
		Exposure duration adult (years)	30	30	24	24
		Body weight (kg) (child)	16	NA	16	16
		(adult)	70	70	70	70
	External	External soil exposure frequency (hours/day)	24	19.2[8]	24	ND
		Exposure duration (years)	30	30	30	ND
	Dermal	Dermal soil exposure rate	NC	NC	ND for radioactive	ND
		Exposure frequency	NC	NC	ND	ND
		Exposure duration	NC	NC	ND	ND
		Body weight (kg)* (child)	16	NA	16	ND
		(adult)	70	NA	70	ND
Air	Inhalation	Inhalation rate adult (m^3/d)	20	20	20	20
		Inhalation rate child (m^3/d)	8.8	NA	ND	ND
		Exposure frequency (days/year)	365	292	365	ND
		Exposure duration (years)**	30	30	30	30
Ground-water	Ingestion	Groundwater ingestion rate (L/d)	3	2	2	2
		Exposure frequency (days/year)	365	365	365	ND
	Inhalation	Groundwater inhalation rate (m^3/d)	NC	NC	15	ND
	Dermal	Dermal exposure rate (min)	NC	NC	10	ND
Surface Water	Ingestion	Surface water ingestion (L/d)	NA	NC	2	[9]
	Inhalation	Surface water inhalation (m^3/d)	NA	NC	15	ND
	Dermal	Dermal exposure rate (time)	NA	NC	ND for radioactive	ND
Sedi-ment	Ingestion	Sediment ingestion rate (mg/d) (child)	NA	NC	200	200
		(adult)	NA	NC	100	50
	Dermal	Dermal exposure rate (mg) (child)	NA	NC	ND	ND
		(adult)	NA	NC	ND	ND
Biota	Dairy	Dairy consumption rate (l/d)	0.27	0.27	300 g/d	ND
		Dairy exposure frequency (days/year)	365	365	365	ND

[5] Washington Department of Health Hanford Guidance for Radiological Cleanup, 1997, Rev. 1.
[6] MTCA does not provide for pathway analysis; instead, parameters are given in order to calculate a cleanup level in various media. As a result, pathways such as external exposure and the intake of biota (other than fish) are not considered.
[7] For the child analysis, six years exposure is assumed as a child, and 24 years as an adult.
[8] The Hanford Guidance document breaks down the time spent in the contaminated area to 60% indoors, 20% outdoors, and 20% offsite.
[9] Surface water cleanup levels for MTCA are based upon fish ingestion.

		Rural Resident Scenario	Hanford Guidance[5]	HSRAM	MTCA[6]
Media/Pathway	**Exposure Parameters**	**Exposure/Intake/Contact Rate**			
Beef	Beef consumption rate (g/d)	162	75[10]	75	ND
	Beef exposure frequency (days/year)	365	365	365	ND
Game	Game consumption rate (g/d)	0	NC	1	ND
	Game exposure frequency (days/year)	365	NC	365	ND
Fish	Fish consumption rate (g/d)	0	14.8	54	54
	Fish exposure frequency (days/year)	365	365	365	ND
Fruit	Fruit consumption rate (g/d)	38	42[11]	42	ND
	Fruit exposure frequency (days/year)	365	365	365	ND
Vegetable	Vegetable consumption rate (g/d)	68	80	80	ND
	Vegetable exposure frequency (days/year)	365	365	365	ND
Poultry	Poultry consumption rate (g/d)	25	25	ND	ND
	Poultry consumption frequency (day/year)	365	365	ND	ND
Eggs	Egg consumption rate (g/d)	27	NC	ND	ND
	Egg consumption frequency (day/year)	365	NC	ND	ND

NC Not Calculated
NA Not Applicable
ND Not Defined
*****Body weights are 16 kg for children, and 70 kg for adults.
******Exposure duration is 6 years for children (when ages are specified for children), and 30 years for adults.

3.2 The Native American Scenario: Offsite Critical Population

The general framework surrounding the scenario was borrowed from DOE/EIS-0189, *Final Environmental Impact Statement for the Hanford Tank Waste Remediation System* [USDOE, 1996]. This scenario combines both traditional and contemporary lifestyles. The traditional activities are hunting, fishing, and gathering plants and materials. Contemporary activities include the use of groundwater for drinking, showering, and watering for plants and animals. The Native American is assumed to live offsite while using the surrounding area for a variety of the activities.

The Native American scenario represents exposures received during a 70-year lifetime by an individual who engages in both traditional lifestyle activities (e.g., hunting and using a sweat lodge) and contemporary lifestyle activities (e.g., irrigated farming). The individual is assumed to spend 365 days per year on the LLRW disposal site over a 70-year lifetime. Some activities are assumed to continue year-round, while others are limited by climate (e.g., frost-free days).

[10] Combined with poultry consumption
[11] Combined with fruits, vegetable, and grain consumption

The main exposure routes via the groundwater pathway are shown in Table 4. They are drinking water, consumption of irrigated vegetables and animal products, ingestion of irrigated soil, external exposure to soil contaminated with irrigation water, inhalation of resuspended soil, and inhalation of water vapors in the sweat lodge.[12]

Table 4 Native American Exposure Pathways

Exposure Pathways	Radionuclides
External exposure from gamma emitting radionuclides in soil while outdoors	Yes
External exposure from gamma emitting radionuclides in soil while indoors	Yes
Inhalation of resuspended soil and dust	Yes
Inhalation of radon and radon decay products from soil containing radium	Yes
Incidental ingestion of soil	Yes
Ingestion of drinking water transported from soil to potable groundwater sources	Yes
Ingestion of water containing contaminants during showering	Yes
Indoor inhalation	Rn-222 only
Dermal absorption of contaminants via skin or puncture wounds	Tritium only
Ingestion of home-grown produce (fruits and vegetables)	Yes
Ingestion of meat containing contamination taken up by cows grazing on contaminated plants	Yes
Sweat Lodge Inhalation	Yes
Ingestion of milk containing contamination taken up by cows grazing on contaminated plants	Yes
Ingestion of meat and eggs containing contamination taken up by poultry feeding on contaminated produce	Yes
Ingestion of locally caught fish	No
Ingestion of organ meats, upland birds, waterfowl, wild bird eggs	Yes
Ingestion of game meat containing radionuclides	Yes

Parameters for the Native American scenarios were derived from Harris and Harper [Harris and Harper, 1997], with supplemental information from the TWRS [USDOE, 1996] and CRCIA [USDOE, 1998] analyses. Ingestion rates of native foods are based on surveys cited in Harris and Harper. The EPA vegetable ingestion rate was ratioed into “root” and “leafy” by the proportions referenced from Hunn [Hunn, 1990]; i.e., 1300 g/d roots and 1400 g/d other vegetables for at total of 2700 g/d vegetables. Ingestion of animal organs and wild bird meat was accounted for by increasing the total meat and poultry intake rate. Animal organs were assumed to have contaminant concentrations 10 times the concentration of other tissues, and the organ intake rate was assumed to be 10 percent of the intake rate of other animal tissue.[13] Note, however, that ingestion of animal products is unlikely to be a significant pathway. Buried waste must be brought to the surface for it to have any effect on the wild animal population. Contaminated waste which is brought to the surface would be distributed in a limited area, small in comparison to the home range of the animal. Exposure times for soil were assumed to

[12] As discussed in Section 4.2.4, groundwater inhalation while showering is shown to not significantly contribute to dose.
[13] The assumption of 10 times the concentration in organ meats is over-conservative for most radionuclides of interest for the groundwater. Cl-36 distributes itself uniformly in the body, so no tissue or organ concentration is enhanced. Tc-99 has an overall organ (GI tract, kidneys, and liver) concentration about three times greater than the muscle tissue. I-129 deposits in the thyroid only with the remaining fraction (about 70%) being directly excreted, so no enhanced concentration would likely be found.

last 12 hours a day for 365 days, or 180 days/year for 24 hours. Table 5 shows the exposure parameters specific for the Native American scenario.

The Native American scenario represents the use of a subsistence Native American lifestyle that includes contemporary activities such as irrigated agriculture, as well as activities such as hunting and the gathering of plants and materials.

Table 5 Exposure Parameters Comparison for the Native American

		Native American-Specific Exposure Parameters	EIS LLRW disposal site Scenario	TWRS	CRCIA	Harris and Harper
Media	**Pathway**	**Exposure Route**	**Intake/Contact**			
Soil	Ingestion	Soil ingestion rate adult and child (mg/d)	200	200	200	200
		Soil exposure frequency (d/yr)	180	365	365	180
		Exposure duration child (yr)	6	6	ND	ND
		Exposure duration adult (yr)	70	64	70	70
		Body weight child (kg)	16	16	ND	ND
		Body weight adult (kg)	70	70	70	70
	External	External exposure time soil (h)	24	24	24	24
		Soil exposure frequency (d/yr)	180	365	365	180
		Exposure duration adult (yr)	70	64	70	70
		External shielding factor	0.8	0.8	0.8	0.8
	Inhalation	Inhalation Rate - child (m^3/d)	8.76	15	ND	ND
		Inhalation Rate - adult (m^3/d)	30	30	30	20
		Soil exposure frequency (d/yr)	180	365	365	180
		Exposure duration child (yr)	6	6	ND	ND
		Exposure duration adult (yr)	70	64	70	70
		Mass loading g soil/m^3 air)	F(activity)	$1.0x10^{-4}$	$1.0x10^{-4}$	$1x10^{-5}$
Water, food		Fruit ingestion rate (g/d)	231	330	330	231
		Vegetable ingestion rate (g/d)	343 (165 root + 178 leafy)	330	330	343
		Meat ingestion rate (g/d) This includes organ meats at 10 times the meat concentration, and consumed at 0.1 frequency of meat. (animal protein, organs, upland birds, waterfowl, wild bird eggs)	275 (250 meat + 25 organ)	341	337	250 (250 meat + 25 organ)
		Milk ingestion rate (L/d)	.49	0.6	0.6	0.49
		Food ingestion duration (year)	70	70	70	70
		Food ingestion frequency (d/yr)	365	365	365	365
		Water ingestion rate - child (L/d)	1.96	1.5	ND	ND
		Water ingestion rate - adult (L/d)	5.01	3	3	3
	Inhalation	Sweat lodge Water Use rate (L/h)	4		4	4
		Sweat lodge Equivalent hemisphere Diameter (m)	2			2
		Sweat lodge exposure rate (h/d)	1	1	1	1
		Sweat lodge frequency rate (d/yr)	365	365	365	365
		Inhalation Rate - child (m^3/d)	15	15	ND	ND
		Inhalation Rate - adult (m^3/d)	30	30	30	20
Air	Inhalation	Inhalation Rate - child (m^3/d)	15	15	ND	ND

		Native American-Specific Exposure Parameters	EIS LLRW disposal site Scenario	TWRS	CRCIA	Harris and Harper
Media	**Pathway**	**Exposure Route**	**Intake/Contact**			
		Inhalation Rate - adult (m^3/d)	30	30	30	20
		inhalation exposure (h/d)	24	24	24	24
		Inhalation frequency (d/yr)	365	365	365	365

ND Not Defined

NOTE: Child parameters for food intake for the Native American are based upon the relative fraction of rural resident child intake, as compared to the rural resident adult. This fraction is then multiplied by the Native American adult to obtain the child intake rate for the Native American child.

Included as part of the table for the Native American parameters is a comparison of the exposure parameters recommended in the Tank Waste Remediation System (TWRS) EIS [USDOE, 1996], the Columbia River Comprehensive Impact Assessment [USDOE, 1998], and the Harris and Harper guidance on Native American Subsistence. A review of the table indicates that when differences between the three references exist, the Harris and Harper document is used as the default. The one exception to this is the decision to use a 30-m^3/day inhalation rate as opposed to 20 m^3/day.[14]

The Native American Sweat Lodge

Use of a sweat lodge is unique to the Native American scenario. The sweat lodge is similar to a steam bath, where high temperatures are combined with a humid environment. The potential ability of the liquid contaminants to become airborne during the flashing of the water to steam on the rocks of the sweat lodge makes this portion of the scenario of particular importance, as the radiological impact of an inhaled contaminant far exceeds the radiological impact of a similar quantity of an ingested contaminant.[15] The Native American adult is assumed to spend 1 hour/day in a sweat lodge.

To briefly describe some of the central parameters of a sweat lodge, the temperature ranges anywhere from 120° to 200° F. Approximately one gallon of water is used per hour. The water that is used to create the steam is heated prior to application on the rocks. The rocks are rotated from the fire to ensure that they stay hot. Estimated temperature of the rocks is 500°F to 600 °F.

Children are known to also participate in the sweat lodge, although their time spent is less frequent and the duration is only 10-15 minutes. It should also be noted that it is common for elders to participate in sweat lodges several times a day for hours at a time. For the Native American adult, an additional two liters of water is assumed to be

[14] The inhalation rate change is based upon a request by Stuart Harris, Confederated Tribe of the Umatilla Indian Reservation.
[15] Briefly, as the steam is vaporized on the hot rocks, liquid droplets are propelled out with the steam. These liquid droplets have not fully transitioned to steam yet. This has an impact for the air concentration calculated for a given volume and temperature, as the steam tables would not take into consideration the liquid droplets. The contaminants of interest for the groundwater are not volatile for the temperatures of concern in a sweat lodge.

consumed during their time in the sweat lodge to account for the water loss due to sweating.

3.3 The Rural Resident Intruder Scenario

Section 3.0.2 discussed the concept of institutional control, which prevents living on the LLRW disposal site. Should there be a lapse of institutional controls, an individual may accidentally live on the site without the knowledge that she/he is residing on the LLRW disposal site. Although significant impediments are in place to ensure that such an intruder condition does not occur, the intruder scenario is designed to estimate the dose to such an individual. The intruder analysis is in direct contrast to an individual who intentionally lives on the LLRW disposal site, disregards site markers, and removes or uncovers contaminated waste.

The onsite intruder, rural resident requires a well in order to live, grow crops, and feed livestock in an arid climate. This scenario is identical to the offsite rural resident with the single exception that, when drilling the well, the onsite intruder removes contaminated well cuttings to the surface. This scenario identifies and quantifies the dose estimate as a result of bringing the well cuttings to the surface, and adds this to the exposure as a result of using the contaminated well water (see Section 3.1, the offsite rural resident). The pathways of exposure for the intruder are similar to the irrigation pathways for the rural resident and include contaminated plant ingestion, soil ingestion and inhalation (via resuspension), and external radiation from the contaminated soil. The ingestion of animal products further contaminated from well cuttings is not assumed, as the limited amount of contaminated material can at best only be spread to an area of 1000 to 2000 m^2 [U.S. NRC 1981].[16] The animals are, however, potentially contaminated as a result of the use of irrigation water. The area of the contaminated material distributed on the surface is conservatively assumed to sufficiently encompass the perimeter of the house, thereby contributing to an indoor dose from external radiation.

The adult rural resident intruder is assumed to spend all of his/her time on the LLRW disposal site, 60% of which is spent indoors and 40% outdoors. Of the time spent outdoors, 60% (of the total 2,500 m^2) is assumed to be spent within the assumed 1,500 square meter surface contaminated area.[17] In the case of individuals from six to 20 years of age, time is allocated for attending school. The school attendance time is assumed to take away from the time that children spent outdoors, leaving the indoor time for children the same as for the adult. The remaining outdoor time for the children ages 6 to 20 years is assumed to take place within the 1,500 square meter surface contaminated area.

The exposure pathways and parameters for the rural resident intruder scenario are the same as for the offsite rural resident. However, the source term is significantly larger (see the source term discussion in Section 3 for a list of specific contaminants), as the intruder is exposed to a greater quantity of radioactive contamination. The offsite

[16] The contribution of dose to humans from animals, were they to be included in the dose estimate, would have a contribution similar to that of the plant contribution (<1%).
[17] If the contaminated material were spread over 2,500 square meters, the external dose estimate would remain the same, as the concentration would decrease by a commensurate amount.

intruder, by comparison, is only directly exposed to the contaminated waste as a result of irrigation and diffusion and resuspension from intruder activities.

3.4 The Native American Intruder Scenario

The Native American intruder scenario utilizes the same exposure parameters as the offsite Native American scenario. The Native American intruder assumptions for access to the buried waste are identical to the intruder rural resident. Please refer to the pathways and parameters located in Tables 4 and 5, and the intruder waste removal discussion in Section 3.3 for review.

3.5 The Intruder Construction Scenario

This scenario addresses the potential risk to an individual while performing activities in preparation for occupation by the intruder inhabitant (either Native American or rural resident). This scenario assumes that an individual comes into contact with the disposed waste in two ways: (1) excavation work, and (2) well drilling. However, because ‘typical’ excavation activities are not expected to involve depths greater than three meters, and the cover and backfill are approximately five meters in depth, intrusion into the waste due to excavation is considered highly unlikely and is not analyzed.

Construction intruders can be exposed to contamination as a result of drilling a well for an intruder resident. Please refer to Section 4.3.3 for a review of the quantity of waste material removed by the construction intruder well driller. Since it is possible for an individual constructing a house as well as the well driller to become exposed to surface contamination following the drilling of the well, the intruder construction scenario does include the additional contribution to dose as a result of exposure to the newly deposited surface contamination. The pathways of interest for the intruder construction scenario are inhalation/ingestion of resuspended material, and direct exposure. The well driller in the construction scenario is exposed for a period of 40 hours for the construction of the well, and house builder is exposed for 500 hours for the construction of the house. The well driller and the home builder are assumed to be two separate individuals. Table 6 provides a review of the exposure pathways for the construction individuals. Table 7 provides the exposure parameters for the scenario. The construction scenario (well driller) differs from the rural resident scenario in that, although the material is dispersed, it is not tilled into the soil. The well driller scenario uses the same uptake factors for soil resuspension and soil ingestion as the rural resident scenario.

Table 6 Intruder Construction Exposure Pathways

Exposure Pathways	Radionuclides
External exposure from gamma emitting radionuclides in soil	Yes
External exposure from gamma emitting radionuclides in soil while indoors	Yes (for home builder)
Inhalation of resuspended soil and dust	Yes
Inhalation of radon and radon decay products from soil containing radium while outdoors	Yes

Table 7 Intruder Construction Scenario

			Intruder Well Driller	Intruder Construction
Media/Pathway		Exposure Parameters	Exposure/Intake/Contact Rate	
Soil	Ingestion	Soil ingestion rate (mg/d)	50	50
		Exposure frequency (hours)	40	500
	External	External soil exposure frequency	40	500
		Soil attenuation factor	0.8	0.5
Air	Inhalation	Inhalation rate m^3 /hr)	1.2	1.2

4.0 DOSE/RISK ANALYSIS METHODOLOGY

This section describes the methodology used to calculate impacts for the general population, Native Americans, and construction individuals. The discussion of the methodology is divided into the exposure pathways. The pathways are:

- Groundwater
- Soil
- Air
- Food
- Surface water

Food is included as a separate exposure pathway even though contamination of food products actually occurs through water, soil, and air contamination. The food pathway was separated so its impact was clearly shown.

The analysis supporting the dose and risk calculations is applied to all scenarios by changing the parameters or slightly modifying an equation. For brevity, the onsite analysis refers to the intruder analysis. The calculations supporting the ingestion and inhalation pathways are borrowed in part from Kennedy and Strenge [Kennedy and Strenge, 1992]. Calculations for the radon pathway are obtained, with a few modifications, from NRC Reg Guide 3.64 [U.S. NRC, 1989] and the RESRAD manual [Yu, et al, 1993]. The carbon 14 diffusion estimates, although a small contributor to dose, are derived by Dr. Man-Sung Yim [Yim, 1997], with the supporting dose calculation methodology taken from RESRAD [Yu, et al, 1993]. Finally, external dose estimates utilized Federal Guidance Report #12 [Eckerman and Ryman, 1993] and the MICROSHIELD computer code [Grove Engineering, 1998].

The dose calculations contained in this report are intended to represent the maximally exposed individual (MEI) for the rural resident analysis, generally taken to imply the upper 95% confidence interval on the mean, and the average exposure of the critical group, the Native American. All of the calculations are performed using a single point dose estimate. The assumptions supporting the single point estimates are conservative and are intended to ensure that the dose projections are sufficiently protective of human health. Uncertainty analysis is performed on the dose projections in Chapter 10.

The conversion of the estimated dose to risk is performed using the recommended value from ICRP 60 [ICRP, 1990]. This value, 0.0005/Rem for the general population, and 0.00040/Rem for occupational workers, is a widely applied fatality coefficient and should allow for comparison of radiological risk with other studies.

Modeling Assumptions

The assumptions supporting the groundwater analysis are provided in the Groundwater Analysis Section of this EIS. Among other items, the groundwater section outlines the infiltration estimates for the various covers, the specific parameters assumed for each radionuclide, and the assumptions used in determining the source term for the groundwater analysis. Source term assumptions are provided in Section 4.1 that follows. Other assumptions used in the analysis of the impacts to individuals are included in the specific sections discussed throughout Section 4 but are briefly outlined below:

- All source term is disposed of at the waste site on the first day of operations, and covered immediately with a final cover. This assumption conservatively places source term at the site for a longer period but does not take into account the 30+ years that the waste is in place without a final or low infiltration cover.

- The entire site contains a single homogeneous source volume. This assumption is conservative because waste is not homogeneous and an intruder may contact areas of lower concentration waste. For the same reason, the assumption is potentially unconservative in that the potential exists for specific locations to contain relatively higher quantities of radioactive materials that could potentially cause greater impact.

- For all analysis with the exception of radon, no credit is given to container integrity. The lifetime of a typical 55-gallon carbon steel drum is expected to be about 30 years [Yim, 1997] and would serve to limit both the production of gases and the infiltration of contaminants to the groundwater. For radon analysis, no emanation is assumed from sealed radium sources (typically encased within concrete) for 500 years.

- Institutional controls are assumed to exist on the site for 107 years. This includes seven years of active maintenance that follows once the site is closed. Institutional controls of only 100 years for the disposal facility is conservative due to the location of the site within the U.S. DOE complex, and the fact that the maintenance fund for this disposal site is sufficiently large to ensure monitoring indefinitely.

- The food and animal pathway analysis is based upon a non-recycling model. Specifically, the contaminated groundwater that is used for irrigation is applied for scenarios that occur at the end of the groundwater modeling (once the groundwater is contaminated) and are not used as the basis or source of infiltration water. The non-recycling model is used because of the amount of time the site is in existence prior to the assumed lapse of institutional controls, and due to the limited probability of multiple generational intruders on the site, considering its location within the overall Hanford Site.

- The intruder on the site is assumed to drill a well through a trench contacting the waste. This is a conservative assumption because there is a substantial area on the site that contains no waste, and the waste must be sufficiently degraded so as not to be identifiable. This assumption is also conservative as it is possible that an intruder would not come in direct contact with the waste.

Barrier Performance Analysis

The covers used in the alternatives represent a wide range of possible designs. The enhanced designs in particular provide an additional measure of safety for both infiltration as well as gaseous diffusion. Specific assumptions used in the analysis of gas emanation from the waste volume, predominately for radon analysis, are outlined as follows:

- In comparison to a clay barrier, the asphalt barrier is approximately a factor of 10 times more effective. This assumption is conservative, as the water vapor diffusion coefficient for an intact barrier is estimated as $2x10^{-5}$ cm^2/s [Kincaid, et al, 1995]. Kincaid's analysis indicated that cracks in the asphalt barrier have the potential to increase the diffusion rate by a factor of two for a single large crack. No upper bound estimate was provided for the total diffusion for a degraded barrier by Kincaid, but a factor of 100 times less effective than an intact barrier is assumed to be sufficiently conservative to model the performance of the asphalt barrier. The degraded barrier performance is assumed for the entire analysis period.

- A synthetic barrier such as an HDPE liner is essentially impermeable to the infiltration of water [Fayer, 1999b] or the diffusion of gas when the material is intact and the welds between sheets of the barrier are securely sealed. Estimates of the long-term viability of this barrier are somewhat more uncertain. Until more information is available on the long-term viability of a synthetic barrier for thousands of years, it is assumed for the gaseous analysis that the barrier is not effective at all in reducing the emanation of a gas. This assumption is quite conservative.

- A clay barrier performance varies depending upon a number of conditions, such as the moisture content, clay content in the barrier, type of clay, etc. The diffusion coefficient for the clay barrier is based upon the use of an empirical formula developed by Rogers and Nielson [Rogers and Nielson, 1991] as well as the clay material properties as defined in RAETRAD, a software code developed by Rogers & Associates [Nielson, et al, 1993].

4.1 Source Term

This risk assessment is based on a source term that was calculated from disposal manifests, beginning in 1965 through 1996 [Thatcher and Elsen, 1999]. The source term for the analysis includes all radioactive waste disposed at the site, including both low-level and NARM waste. The source term does not include chemical waste. Future projections for low-level and NARM waste were based upon the 1993 through 1996 disposal volumes and the source term expected from the disposal of the Trojan and Washington Public Power Supply reactor vessels. Use of the source term for the risk assessment required certain assumptions or screening tools. These are:

- The total LLRW disposal site inventory contains about 622 separate isotopes. A majority of these radionuclides are short-lived or of minimal activity. In order to focus the analyses on the radionuclides with the highest likelihood of contributing to a dose, screening tools/assumptions were developed. The first screening tool assumes that any isotope with a half-life of less than 5.5 years cannot contribute to dose when the institutional control of 107 years is considered. This screening tool is based on the assumption that the institutional control will be effective at keeping people off the LLRW disposal site for at least 107 years. This first assumption specifically excludes any impact from all radionuclides with half-lives less than that of cobalt 60, including cobalt 60.

As an example, the 1996 undecayed activity of Co-60 is 552,683 curies. Reducing this activity by 107 years of decay would be calculated as follows:

Equation 1

$$FinalCobaltActivity = 552{,}683Ci * e^{-(\frac{.693}{5.27}*107\,years)} = 0.43Ci$$

The resulting activity of Co-60 107 years later is approximately 0.4 curie, which does not take into consideration the significant amount of decay that occurred prior to 1996.

- The second series of screening tools/assumptions excludes radionuclides with total activities less than 1 curie in 1996. The basis for this assumption relates to the equivalent calculated concentration for a given radionuclide. In order to simplify the impact from uncovering and or removing contaminated waste from a buried trench, the LLRW disposal site is assumed to be one homogeneous waste volume. Taking this homogenous waste volume of the actual trenches (not the volume between the trenches), and assuming a waste density of 1.26 g/cm^3 [U.S. Ecology, 1996], results in a total waste mass, including fill, of approximately 1.4x10^{12} g of waste material. Taking a 1-curie source, which is 1x10^{12} pCi, and dividing by the total waste mass, results in a concentration of less than 1 pCi/g. For conservancy, Nb-94, with a total 1996 activity of 0.98 curie, is included in the analysis.

- Decay of radionuclides is considered, as is progeny ingrowth.[18]

4.1.1 Source Term Considerations for Groundwater Modeling

Of the total 600+ radionuclides disposed at the LLRW disposal site, very few have a long enough half-life, large enough source term, and are soluble enough to cause a potential impact to groundwater. The radionuclides that are considered in the groundwater analysis are H-3, Cl-36, Tc-99, I-129, U-235, and U-238[19] [Dunkelman, et al, 1998].

[18] Radionuclides included in the 1965-1996 source term are not decayed prior to 1996. The 1965-1996 source term is decayed as of 1996. All projections of future activities are decay corrected.

[19] Carbon 14 was modeled as a gaseous release at the disposal site and was therefore not considered in the groundwater analysis.

4.1.2 Radionuclides with Source Term Uncertainty

There are a few radionuclides with known source term errors. Those radionuclides are Tc-99, I-129, U-235, and U-238. The Tc-99 and I-129 error is due to the reported activity being based upon scaling factors (the ratio between the difficult-to-detect I-129 and a readily measurable isotope such as Co-60). In actual practice, the minimum detectable activity (MDA) of I-129 and Tc-99 was used for the calculation of the scaling factor and resulted in overestimates of the actual quantities of I-129 by anywhere from 100 to 10,000 [U.S. NRC, 1996].

The uranium source term, U-235 and U-238, is considered under-reported due to the failure to convert mass disposal quantities into activity. This under-reporting occurred during the 1960's and early 1970's. For the modeling for this analysis, the U-235 source term is multiplied by a factor of two, and the U-238 inventory is multiplied by a factor of ten to account for the potential uncertainty.[20] These gross overestimates of activity do not have a significant impact on dose, due to uranium being solubility-limited.

4.2 Groundwater

Groundwater contamination has the potential to impact the greatest number of individuals. The primary route for exposure to individuals is direct ingestion of groundwater used as drinking water. Other avenues for exposure include exposure via inhalation and ingestion while showering, or inhalation while in steam rooms, as is the case for the Native American sweat lodge. The use of contaminated groundwater also impacts a number of other pathways, such as soil. The combination of the water and resulting soil contamination, as is the case for the use of groundwater in irrigation scenarios, can also impact food and animal products. This, in turn, may lead to potential exposures to individuals. Please refer to the groundwater section of this EIS for further discussions of the groundwater analysis used in estimating the contaminant concentration. The groundwater concentration estimates for the various alternatives are included in Table 8.

[20] Recent evidence indicates that the U-235 source term is grossly over-estimated. It also appears that the U-238 estimates are roughly 20% greater than the original estimates. Final corrections to the uranium source term are expected sometime during the year 2000.

Table 8 Summary of Predicted Groundwater Concentrations for the Alternatives* (pCi/l)

Radionuclide	Alternatives							
	Proposed Action	Filled Site	Site Soils Cover	Thick Homog-eneous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite – Year 2056	Enhanced Bentonite - Year 2000
Chlorine 36	36	38	45	20	20	20	20	19
Technetium 99	490	590	580	270	270	270	270	250
Iodine 129	3.9	4.5	4.6	1.9	1.9	1.9	1.9	1.8
Uranium 235	0.23	0.23	2.3	0.057	0.057	0.057	0.057	0.057
Uranium 238	0.036	0.036	0.36	0.0089	0.0089	0.0089	0.0089	0.0089

*Estimates are only shown for those radionuclides that are expected to reach the groundwater in less than 10,000 years.

4.2.1 Groundwater Ingestion

Adults in a rural resident scenario are assumed to drink three liters of water per day.[21] Native Americans are assumed to drink five liters of water per day. The two additional liters are due to the additional water use during their time in the sweat lodge. Children for either scenario are assumed to drink a quantity that is a function of their age. The formula for calculating the drinking water dose is as follows:

Equation 2

$$Dose_{dw} = \frac{C_w}{27} * Q_w * DCF * 10^5$$

Where:

- $Dose_{dw}$ = Committed effective dose from drinking water (mrem/year)
- C_w = Contaminant groundwater concentration (pCi/l)
- Q_w = Intake rate of water (l/year)
- DCF = 50 year committed effective dose conversion factor for ingestion of contaminants (Sv/Bq)[22]
- 10,000 = Converts Sieverts (Sv) to mrem

[21] Three liters/day of water ingestion is considered a reasonable upper bound intake amount for arid climates. Further support for this value can be obtained from reviewing the supporting literature used in the EPA *Exposure Factors Handbook* [U.S. EPA, 1997]. Briefly, a weighted average is obtained by assuming that increased water consumption of approximately 4 l/d occurs during the hot months (about one-third of the year), and a reasonable upper bound value of 2.3 l/d occurs during the remainder of the year.

[22] For this analysis, both the adult and child dose estimates are calculated using ICRP 60 methodology. Due to the inherent delays in the regulatory process, ICRP 60 methodology has yet to gain acceptance within the United States. However, child dose conversion factors are only available using ICRP 60 methodology. The adult dose estimates are provided using the same methodology (ICRP 60) as the child, for consistency.

- 27 = Converts Bq to pCi

4.2.2 Groundwater Inhalation: Sweat Lodge

The sweat lodge for the Native American assumes that all the water (and contaminants) used is vaporized or entrained in the lodge, and the resulting concentration breathed for the entire duration in the lodge. The formula for calculating the exposure is:

<u>Equation 3</u>

$$Dose_{sweatlodge} = C_w * \frac{Volume_{water}}{Volume_{airinlodge}} * V_{sw} * EF * ED * DCF * \frac{10^5}{27}$$

Where:

- $Dose_{sweat\ lodge}$ = Committed effective dose from sweat lodge respiration (mrem/year)
- C_w = Contaminant groundwater concentration (pCi/l)
- $Volume_{water}$ = Quantity of water used in the sweat lodge (liters)
- $Volume_{air\ in\ lodge}$ = Air volume of the sweat lodge (m^3)
- V_{sw} = Breathing rate while in the sweat lodge (m^3/day)
- EF = Exposure Frequency (days per year exposed)
- ED = Exposure Duration (fraction of day exposed)
- DCF = Dose conversion factor (Sv/Bq)
- $10^5/27$ = Conversion factor from Sv to mrem and pCi to Bq

4.2.3 Groundwater Ingestion while Showering

An individual in either scenario is assumed to ingest 0.01 liters/day of water while showering. The shower water ingestion is a small fraction of the total ingestion of water per day.[23]

4.2.4 Groundwater Inhalation while Showering

An individual in either the Native American or rural resident scenario is assumed to shower for 15 minutes every day. Given the normal temperatures of a shower, about 0.1% of the total water volume is assumed to volatilize, with a corresponding amount of contaminants entrained in the volatilized particles. Other assumptions for calculating the dose include the breathing rate while showering and the total volume of the shower area. Given these parameters and assumptions, it can be shown that groundwater contaminants that are assumed to remain airborne will contribute a fraction of a mrem/y to an individual.[24] As the predicted impacts from any of the five groundwater

[23] Potential exposure via inhalation while showering is generally only considered for volatile organic compounds [Yu, et al, 1993, U.S. DOE, 1996].

[24] For example, assuming a concentration of 500 pCi/l of Tc-99 in the water, 1 m^3/hr breathing rate, 0.1% volatilization for hot water 2.5 m^3 shower volume, 10-minute shower time (80 liters of water) for 365 days/year, and a dose conversion factor of 1.5×10^{-5} mrem/pCi, results in an estimated dose of 1×10^{-2} mrem/y.

contaminants are too small to warrant consideration in the alternatives, further estimates of groundwater inhalation while showering are not considered.

4.2.5 Dermal Absorption of Groundwater

Dermal absorption of radionuclides is not considered in this report. Unlike some chemicals, radionuclides are generally absorbed into the body very poorly [Yu, et al, 1993]. Tritium is an exception to this rule. Tritium, however, is found in very low concentrations in the groundwater, due to the short half-life and relatively small source term.

4.3 Soil

Surface soil is contaminated through three mechanisms:

- The use of contaminated irrigation water
- The uncovering the contaminated waste through intruder activities such as digging a well
- The resuspension and redistribution of contaminated soil

The possibility for plants or animals to uncover or remove contaminated soil is discussed in Section 4.3.5. There are four methods by which exposure to contaminated soil can occur:

- Inadvertent ingestion (Section 4.3.1)
- Resuspension and inhalation (Section 4.3.2)
- External exposure (Section 4.3.3)
- Dermal exposure (Section 4.3.4)

In calculating the dose as a result of soil contamination, it is important to realize that soil contamination can occur through any combination of the three mechanisms. For example, an individual may live and grow crops outside of the contaminated area. Using irrigation water, he/she contaminates the soil over time as a result of the water being contaminated. If an intruder were present onsite, some additional, albeit small, contribution from resuspended material driven offsite could also contaminate the same soil. Similarly, for the intruder, soil would be contaminated through the use of irrigation water as well as through digging up contaminated waste and distributing this throughout the surface soil. For continuity, the calculation of the concentration of a contaminant in the soil is included in Section 3.5, as the equations for the soil concentration are linked with the food ingestion calculations.

4.3.1 Inadvertent Soil Ingestion

Ingestion of contaminated soil is possible as a result of transfer to vegetables, fruits, and hands [Kennedy and Strenge, 1992]. Although the amount ingested depends upon the activities performed and personal habits, a single conservative value is assumed. For the rural resident, 50 mg/day is assumed, while the Native American is assumed to ingest 200 mg/day. Children are also assumed to ingest 200 mg/day. The equation for calculating the ingestion dose is as follows [Kennedy and Strenge, 1992]:

<u>Equation 4</u>

$$Dose_{soiling} = C_{soil} * IR * ED * DCF * 100{,}000$$

Where:

- $Dose_{soiling}$ = Committed effective dose from the ingestion of soil
- C_{soil} = Concentration of soil (Bq/g)
- IR = Ingestion rate of soil (g/day)
- ED = Exposure duration (d/year)
- DCF = Committed effective dose conversion factor for ingestion (Sv/Bq)
- 100,000 = Conversion from Sv to mrem

A modifying factor may also be added to this equation to account for time spent outside of a contaminated area.

4.3.2 Soil Resuspension and Inhalation

Contaminated soil may also result in exposure due to resuspension and subsequent inhalation. For the intruder, exposure may occur from soil contaminated through irrigation water or through the uncovering of contaminated soil. For the offsite individuals, exposure from this pathway may occur from soil contaminated via irrigation water or from material dispersed from onsite. Note, however, for exposure to occur from contaminated material driven offsite, an intruder would have to gain access to the waste. Otherwise, the offsite soil is contaminated only with the radionuclides found in the groundwater.[25]

The resuspension factor does depend upon the activities that are being performed by the intruder. The highest dust loading is related to gardening activities, while the lowest is equated to time spent indoors. The equation for calculating the committed effective dose from inhalation is as follows [Kennedy and Strenge, 1992]:

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[25] Offsite soil contamination from onsite activities can contribute through a number of pathways. The following calculations are therefore calculated as a percentage of the onsite dose. The integral of a time-dependent resuspension factor is 1.4×10^{-4} (d/m) [Anspaugh, 1998]. By multiplying the air resuspension integrated over a year by the deposition velocity (0.001 m/s), by the 0.176 fraction of time the wind blows toward the offsite MEI direction, and by 86,400 s/day, the product yields a dimensionless factor by which the onsite dose from various pathways can then be multiplied. Offsite ingestion and external doses will not exceed 0.2 % of the onsite doses.

Equation 5

$$Dose_{inhalation} = [(V_g * t_g * CDG * C * DCF) + (V_x * t_x * CDO * C * DCF) + (V_r * t_i * (CDI + P_d * RF_r) * C * DCF)] * 10^5$$

Where:

- V_g = Breathing rate for time spent in the garden (m^3/h)
- t_g = Time spent in the garden during a year (hours)
- CDG = Dust loading for activities taking place in the garden area (g/m^3)
- DCF = Inhalation committed effective dose, nuclide and age specific (Sv/Bq)
- V_x = Breathing rate for time spent outdoors (not in garden)(m^3/h)
- t_x = Time spent outdoors (not in garden) during a year (hours)
- CDO = Dust loading for outdoor (not in garden) activities (g/m^3)
- V_r = Breathing rate for time spent indoors (m^3/h)
- t_i = Time spent indoors during a year (hours)
- CDI = Dust loading for indoor activities (g/m^3)
- P_d = Indoor dust loading on floors (g/m^2)
- RF_r = Indoor resuspension factor (per meter)
- 100,000 = Conversion from Sv to mrem

The indoor portion of the above equation differs slightly from the outdoor portion, as it includes contributions from materials blown and soil tracked into the house and resuspended [Kennedy and Strenge, 1992].

4.3.2.1 Calculation of the Offsite Dose Due to Resuspension from Onsite

Section 4.3.2 provides a discussion and method for determining the relative impact to offsite locations as a result of onsite contamination. This method calculated the impact as a result of accumulated soil contamination over time. Soil inhalation, however, depends upon the contaminant concentration in the air, and is determined somewhat differently. The offsite air concentration at any given time would be significantly less than the corresponding accumulated deposition that results in the 0.2% of dose factor calculated in the footnote supporting Section 4.3.2. However, for calculational ease, it is assumed that the contribution to inhalation dose from onsite resuspended material is 0.2% of dose as well.

4.3.3 External Exposure to Soil

External exposure to contaminated soil is generally only a potential hazard for intruder activities.[26] Offsite exposures only occur from the groundwater contaminants, which are not external exposure hazards, or from materials driven offsite (from onsite) which

[26] As discussed in the inadvertent soil ingestion section, groundwater contaminants are not gamma emitters and would not pose an external hazard. The resuspended material from onsite deposited offsite is at most 0.2% of the onsite dose. External contributions from all materials are considered in the supporting documentation to this analysis.

would be low in concentration (<0.2% of the onsite dose). For the intruder, the possible contaminants include the entire waste inventory.

In order for an intruder to bring the contaminated material to the surface onsite, a 12-inch (30 cm) diameter well is assumed to be drilled (see the intruder construction scenario) to 360 feet (110 meters) (50 feet past the presumed groundwater table). Of that 360 feet of material, 37 feet (11.3 meters) are assumed to be contaminated with a homogeneous mix of the source material from the low-level waste.[27] This contaminated material is uniformly spread over a 16,000 square foot area (1,500 square meters) [U.S. NRC 1981, Napier, et al, 1984]. The depth of the contamination is six inches (15 cm), as the material is assumed to be uniformly tilled.[28] The 1,500 square meters allow the calculations to approximate an infinite plane [Napier, et al, 1984] for external dose calculations.

In order to accurately calculate the ingrowth of the progeny (for the intruder) and perform further external exposure calculations, the computer code MICROSHIELD [Grove Engineering, 1998] is used. The MICROSHIELD code calculates the parent and progeny concentrations as well as an estimate of the effective dose equivalent, using ICRP 51 methodology [ICRP 51, 1987].

The external dose contribution analysis for both indoor and outdoor scenarios is performed in the following manner:

1. The concentration in the waste volume was estimated by taking the total source activity per radionuclide and dividing it by the total mass of waste and other fill in the active waste region.[29] The estimate excludes the mass of soil between trenches at the depth of the waste.

2. The volume of waste (0.8 cubic meters) is then removed and uniformly spread over the top 15 centimeters of soil to an area of 1,500 square meters.

3. This surface concentration is entered into the MICROSHIELD code in the form of a perfect disk source, with the dose point (the individual) in the center. The soil used for the analysis is a Nevada Test Site (NTS) dry, sandy soil [Eckerman and Ryman, 1993]. The NTS soil is sufficiently close to the cover material that will be used at the LLRW disposal site.[30]

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[27] Recent trenches have a depth of 45 feet, 37 of which are dedicated to low-level waste. The remaining 8 feet are clean fill to grade.

[28] A volume of 0.8 cubic meter of contaminated material is removed from the well. The 15-cm mixing provides a realistic depth of soil for farming use and also serves to maximize the potential impacts of uptake to plants.

[29] The volume used for dilution has been modified from the 50-million cubic feet value used by US Ecology. WDOH instead used the volume of the waste area excluding the cover material. In order to calculate this, WDOH determined the fill efficiency for each trench (amount of waste per total waste area). This information was then used to determine the total waste area volume for the year 2056, by dividing the projected waste inventory of 20 million cubic feet by the fill efficiency [Ahmad, 1988].

[30] This soil also has the added benefit of being analyzed for comparison with the results of Federal Guidance Report #12 [Eckerman and Ryman, 1993].

4. MICROSHIELD calculates the estimated contribution to dose, using the appropriate buildup and attenuation factors for the soil and air [Grove Engineering, 1988]. As a check on results, the concentrations obtained from the output of the MICROSHIELD code are also used as the input for analysis using Federal Guidance Report (FGR) #12 [Eckerman and Ryman, 1993]. The tables for uniform contamination to 15 centimeters were used. These tables are based upon an infinite plane source.

The general formula used for calculating the external effective dose equivalent for outdoor exposure is as follows:

<u>Equation 6</u>

$$ExternalDose = C * DCF * ED * 3600 * \frac{1500}{2500}$$

Where:

- External dose = Dose in Sieverts (multiply by 10,000 to obtain dose in mrem)
- C = Concentration ($Bq*m^{-3}$)
- DCF = Dose conversion factor, nuclide specific ($Sv*s^{-1}*Bq^{-1}*m^{3}$)
- ED = Exposure duration (hours/year)
- 3600 = Conversion from hours to seconds
- 1500/2500 = Corrects for the time spent within the contaminated area

In the child analysis, the values of ED and time spent within the contaminated area are modified to account for attending an offsite school.

As the contribution is from an external field, a whole body dose is assumed and can be added to the effective dose calculated from internally deposited material. For calculational ease, a shape factor[31] of one (1) was assumed for time spent within the 1,500 square meter contaminated area. Time spent outside the 1,500 square meter area was considered to have a shape factor of zero, thereby contributing nothing to the calculated dose. This assumption is conservative, as the time spent within the 1,500 square meter area would rarely be a perfect geometry, and time spent near the edge would be about half.

Perhaps the largest unknown is the estimated time that an individual spends outside. For the rural resident intruder, since the assumption is made that the individual lives and grows some food at the LLRW disposal site, it is assumed that 60% of his time is spent indoors [Yu et al, 1993], and 40% outdoors.[32] The Native American intruder is assumed to spend equal amounts of time both indoors and out.

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[31] The shape factor is a correction that takes into account irregularly shaped contaminated areas.

[32] The indoor time estimates for this analysis are somewhat lower than the estimates provided in a review performed by the U.S. EPA [U.S. EPA, 1992]. The lesser amount of time spent indoors as compared to the estimated United States average is expected to result from the greater amount of food grown individually.

The external radiation contribution from time spent indoors is calculated in a similar manner to the calculation for the time spent outdoors. It is assumed that contamination is not directly underneath the foundation of the house.[33] An indoor shielding factor of 0.33 [Kennedy and Strenge, 1992] is utilized to account for the shielding provided by the structure of the home, the reduction from an infinite plane source as the home is at the boundary of the contaminated area, and a further reduction to account for time spent indoors away from the walls. The exposure time indoors is 60%, or 5,250 hours per year for the rural resident intruder, and 4,380 hours per year for the Native American intruder. The formula for indoor exposure is:

Equation 7

$$ExternalDose = C * DCF * ED * 3600 * 0.33$$

Where:

- 0.33 = Indoors shielding factor[34]

4.3.4 Dermal Exposure

The absorption fraction for radionuclides on the skin that are absorbed into the blood is generally small, and with the exception of H-3, is not further considered in this analysis. Chemical dermal contact of volatile organics, by comparison, has significantly higher absorption rates and has the potential for contributing to exposure.

In addition to skin absorption, dermal contact with radionuclides may also pose a risk, assuming the contaminant is of a sufficient concentration. Generally speaking, for a contaminant on the skin to pose a hazard, the radionuclide must be a strong beta or gamma emitter. In these instances, the risk from exposure does not sufficiently contribute to dose, as the contamination is on the arms and legs. The hazard from these exposures is from burns or ulceration, assuming the contamination is present long enough or in sufficient concentration. As an example, the strongest external hazard present in post-closure analysis is Cs-137. An assumption of closure in the year 2056, with potential access in 2163, results in a Cs-137 concentration of 11 pCi/g to the intruder. To calculate the concentration per centimeter on the body would be as follows:

Equation 8

$$SkinContamination = C_s * SAF$$

Where:

- C_S = Soil contamination in pCi/g

[33] Directly underneath means contaminated waste from the well cuttings, not the contaminated waste still buried in the trenches.
[34] Without considering the shielding provided by the housing structure, the MICROSHIELD code estimates that the external dose rate would be reduced by approximately 90% for an individual standing 10 feet from the edge of the contaminated area (the wall of the home). The indoor shielding factor of 0.33 is therefore considered conservative.

- SAF = Skin adherence factor (g/cm^2)

A standard skin adherence factor is 0.2 mg/cm^2 [USDOE, 1996]. For cesium, the result is a concentration of 2.2×10^{-3} pCi/cm^2. This contaminant concentration would need to be at least nine (9) orders of magnitude greater before deterministic risks such as skin burns became an issue.[35] Dermal exposure for radionuclides is therefore not included in this analysis.

4.3.5 Direct Contact with Buried Waste

Potential biotic intrusion (i.e., plant roots and burrowing animals) into the waste trenches was evaluated. The proposed depth of the trench cover varies from a minimum of 11'6" for the Site Soils and Enhanced Bentonite - Year 2000 Closure Alternatives, to 16'4" for the Proposed Action and Filled Site closure alternatives. In addition, three of five closure alternatives include covers with characteristics that inhibit penetration by plant roots (e.g., bentonite layer, asphalt). DOE (1995) summarized the published information on plant rooting and animal burrowing depths for Hanford, that included a study by Klepper on the rooting depths of deep-rooted plants common to the 200 Areas that are adjacent to the LLRW disposal site. The deepest burrowing animal was the harvest ant at 8.9 feet, and the badger was the deepest burrowing mammal at 8.2 feet [U.S. DOE, 1995]. Klepper found that eight of the 14 plant species investigated had average maximum rooting depths exceeding 4.9 feet. The species with the greatest average maximum rooting depth are antelope bitterbrush (9.7 feet), big sagebrush (6.6 feet), and spiny hopsage (6.4 feet). Variability in maximum rooting depth among individual plants of a species was low (i.e., coefficient of variation ranged from 0.03 to 0.20 among species), suggesting that rooting depth may be limited by available soil moisture. Furthermore, the ecological risk assessment regulations currently under development by the Department of Ecology state that a terrestrial evaluation can be completed and no further analysis required for sites where the soil contamination is at least six feet below the soil surface. Based upon this information, the direct contact exposure pathway of plants or animals to waste buried under covers will not be considered for all the closure alternatives.[36]

4.4 Air

This section describes the process for evaluating the expected dose from exposure to gaseous radionuclides at the LLRW disposal site. This analysis considers three potential contributors to dose: radon (and progeny), carbon 14, and tritium. Chlorine 36 is also a potential gaseous emitter but is considered to impact via the groundwater. The discussion for the three radionuclides describes the numerous considerations involved in analyzing the potential impact to individuals indoors, outdoors, and offsite.

Of potential concern is the possible impact to LLRW disposal site boundary locations prior to the end of institutional control. As the analysis for the groundwater pathway

[35] Based upon the NCRP-recommended limit of 75µCi-hrs of exposure [NCRP, 1989].
[36] This entire chapter is borrowed from the *Chemical Risk Assessment for the Commercial Low-Level Radioactive Waste Disposal Facility, Richland, Washington* [Kirner Consulting, Inc., 1999].

does not predict an impact prior to the end of institutional control, gaseous diffusion is the only possible mechanism by which exposure to an individual can occur. Due to the long half-life of radium 226 (the parent of radon) and of carbon 14, the offsite estimates for these two radionuclides can be applied to any time period during the institutional control period, due to the small amount of decay. Tritium, due to its short half-life, decays considerably during the institutional control period. Specific calculations are therefore performed for tritium to estimate the potential impact at the proposed LLRW disposal site closure date.

4.4.1 Radon Contribution Analysis

Radium 226, with a half-life of 1600 years, alpha decays to radon 222 with a half-life of 3.8 days. Radon is a gas, and as such, a fraction of the radium 226 that decays escapes the confines of the soil column and migrates toward the surface. This diffuse radon can accumulate in houses through cracks in the floor, around floor penetrations (such as drainpipes), and through the concrete floor. A portion of the radon in the air is respirated and retained in the lung where the radon daughters (Po-218, Bi-214, Pb-214, and Po-214) deliver a dose that is approximately 100 times greater than the dose of radon 222.[37]

For the proposed alternatives, cover depth and the addition of a clay layer are two controllable factors that drive the estimated radon flux from the soil. When considering the thickness of the cover for radon reduction potential, gravel layers are not assumed to have any mitigating effect. Clay, however, has a tremendous impact on radon emanation. A clay barrier is estimated to reduce the predicted emanation rate by a factor of 2.5.

The radon discussion is divided into three sections: indoor radon, outdoor radon to the intruder, and offsite radon contribution. Radon is predominately a contributor to dose while indoors, as the gas has a greater opportunity to accumulate in a home without the benefit of the free exchange of air. As a result, a majority of the focus is spent on determining the largest contribution to dose: the indoor radon pathway.

4.4.1.1 Indoor Radon Contribution

One driving assumption for the indoor radon dose is that an intruder will build a basement whose depth does not exceed the seven-foot depth of the barriers (the sand/bentonite layer) found in most of the designed covers, thus reducing the dose received from the radon daughters by a factor of about 2.5. Building requirements for access and egress from a basement dictate that a seven-foot excavation depth is reasonable for new construction homes [Aleshire, 1997]. Based upon this information, DOH assumed a seven-foot building foundation excavation depth.

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[37] In addition, Rn-220 (thoron), the daughter of Th-232, was evaluated as not being capable of significantly contributing to dose, as the half-life for Rn-220 is sufficiently short that diffusion through the cover layer is not considered possible due to the significant decay of the Rn-220 concentration with depth [NCRP, 1987a]. For Th-232 removed by intruder activity to the surface soil, the inhaled dose from thoron is about one seventh that of radon [NCRP, 1987a], assuming equivalent concentrations of Rn-222 (radon) and Rn-220 (thoron).

4.4.1.1.a Methodology

The conversion of a radium soil concentration to a dose to an individual involves a number of assumptions and approximations. The flow path of working from a soil concentration to a dose using deterministic values is discussed below.

For modeling purposes, the layers beneath the basement slab were assumed to be a single barrier (if present), followed by a layer of site sand. The characteristics of the site sand are assumed to apply to both the cover and the waste volume [Phillips, 1998]. The waste volume was assumed to be approximately 35 feet deep. The radon flux from the waste volume was calculated using the formulas provided in NRC Regulatory Guide 3.64 [U.S. NRC, 1989]. Further details regarding the flux calculations are located in the supporting documentation [Thatcher, et al, 1998].

- The formula for the diffusion coefficient is based upon updated information [Rogers and Nielson, 1991]. The formula is as follows:

<u>Equation 9</u>

$$D_c = D_o * p * e^{(-6*S*p-6*S^{14*p})}$$

Where:

- D_c = Diffusion coefficient for radon in soil (cm²/s)
- D_o = Diffusion coefficient for radon in air (cm²/s)
- p = Soil porosity
- S = Volume fraction of water saturation

This updated diffusion coefficient equation is based upon over 1,000 additional radon diffusion coefficient measurements for soils, and over 600 additional measurements for uranium mill tailings than is recommended in NRC Reg. Guide 3.64. The updated empirical equation generally results in lower estimates of the diffusion coefficient, as compared with the previous equation.

- DOH modified the source term provided in the US Ecology closure plan, to account for a portion of the radium disposed in a sealed container.[38] The reduction in the radon diffusion coefficient was accounted for by reviewing the disposal records for 1987, 1988, 1989 [U.S. NRC, 1990], 1994, 1995 [Blacklaw, 1996], and 1996 [Elsen, 1997]. The discrete (sealed) radium concentration is 81% of the total radium disposed for those years. The NRC [US. NRC, 1982] requires the assumption that all material (i.e., concrete) will degrade within 500 years. As a result, at 500 years following closure, the entire radium activity is considered available for diffusion.

- A conservative 20% reduction factor [Landman and Cohen, 1983] is applied to the radon flux value to take into account the decreased emanation rate through a

[38] The radium disposed as a sealed source is generally contained within 2500 psi concrete and would not contribute to the overall radon gas emanation rate.

cracked concrete floor (concrete without cracks would have an emanation rate of less than 1%, as compared to the bare soil flux).[39]

- Assuming a ventilation rate of 0.5 hr^{-1} [Yu, et al, 1993], the calculated steady-state radon concentration is calculated. This concentration includes a factor [Marcinowski, et al, 1994] to correct basement concentrations to concentrations in living spaces.[40] The formula for calculating the indoor concentration is as follows [Yu, et al, 1993]:

  Equation 10

$$C_i = \frac{(\frac{J_i}{H} + v * C_o) * 0.38 * 0.20}{(\lambda + v) * 1000}$$

  Where:

  - C_i = Indoor concentration (pCi/l)
  - C_o= Outdoor concentration (pCi/l)
  - J_i= Radon flux (pCi/m²*s)
  - H = Room height (m)
  - v = Ventilation rate (s^{-1})
  - λ = Decay constant of radon (s^{-1})
  - 1000 = Conversion from m^3 to liters
  - 0.38 = Corrects basement reading to predominate level of living space
  - 0.20 = Provides an adjusted bare floor diffusion rate to take into account a cracked concrete floor

- The concentration of radon daughters (the contributors to dose) in the air (of a room) is significantly less than the concentration of radon itself, due to a number of factors. Those factors include radioactive decay, plateout (settling onto walls and other surfaces of a room), and physical removal by ventilation. The application of an equilibrium correction factor 'F' accounts for the lower concentration of radon daughters measured in an environment. The equilibrium F factor is highly correlated with ventilation rates in a home [Swedjmark, 1983]. As ventilation rates for United States homes range from .35 to 1.5 exchange volumes per hour [Yu, et al, 1993], the equilibrium equivalent concentration (EEC)[41] is approximately 33% to 50% [Swedjmark, 1983] of the radon concentration.[42]

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[39] The relatively large fraction of radon passing through the cracked concrete floor also serves to model for pressure-driven radon entry (advection), in addition to diffusion.

[40] The National Residential Radon Survey conducted in 1989 and 1990 collected data for all spaces of a home. Total basement concentration (living and non-living spaces) was 122.1 Bq/m^3 (arithmetic mean). The average concentration in a home was found to be 46.3 Bq/m^3. The resulting correction from basement to total home is 0.38.

[41] EEC is the radon concentration in equilibrium with the short-lived daughters.

[42] NOTE: A linear equation for the radon concentration as a function of ventilation rate was used, as the NCRP-recommended value (.5/.3/.2) for Po-218, Bi-214, and Pb-214 does not account for fluctuations in the ventilation rate.

- The equilibrium concentration of radon daughters in a home is then converted to a working level[43] (EEC/100), a common term for expressing radon exposure. The formula for calculating the working level (WL) is:

  Equation 11

  $$WL\ (pCi/l) = 0.00104[^{218}Po] + 0.00514[^{214}Pb] + 0.00382\ [^{214}Bi]$$

- The result is then converted to working level months per year (WLM/year). The WLM/year is the exposure rate in WL, multiplied by the hours of exposure (per year for residential exposures), divided by 170 hours (the number of hours per month that a uranium miner typically spends in the mines). The onsite rural resident is assumed to spend 60% of his/her time indoors, resulting in an exposure time of approximately 5,250 hours/year. The formula for the WLM/year is as follows:

  Equation 12

  $$WLM/yr = \frac{WL * ExposureTime}{170 hours}$$

- The effective dose to an individual is estimated by using an effective dose per unit exposure conversion factor of 830 mrem/WLM [Porstendorfer and Reineking, 1999]. This value is based upon ICRP 66 [ICRP, 1994] lung dosimetry, and estimates of 'normal' indoor particle concentrations.[44]

4.4.1.2 Outdoor Radon Contribution

For the intruder scenario, the individual also receives a dose from the ambient concentration of radon while outdoors. Two sources of radon contamination exist for the intruder; the first is the buried contaminated waste on which the intruder lives, and the second is the contaminated material brought to the surface as a result of drilling a well. The combination of these two sources is added to provide the estimate of the outdoor radon contribution.

The surface flux estimate can then be utilized to determine an ambient air concentration onsite, using the following formula [Yu, et al, 1993]:

Equation 13

$$C_{Radoninair} = \frac{\left\{0.5 * EVSN * \sqrt{A}\ \right\}}{\left\{\ H_{mix} * U\ \right\}}$$

[43] Working level is defined as any combination of short-lived radon daughters in one liter of air that will result in the ultimate emission of 1.3 X 10^5 MeV of potential alpha energy [NCRP, 1988].
[44] Although dosimetry is used in this EIS to estimate the resulting dose, the ICRP has concluded that the use of epidemiology of radon in mines is more direct, and therefore involves less uncertainty and is more appropriate for the ICRP 65 report than the indirect use of the epidemiology of low-LET radiation from Japanese data [ICRP 65]. The ICRP recommends that the dosimetric model should not be used for the assessment and control of radon exposures.

Where:

- $C_{\text{Radon in air}}$ = Average concentration of radon in air over a contaminated area (pCi/m^3)
- 0.5 = Default time fraction wind is blowing toward individual (dimensionless)
- EVSN = radon flux (pCi/m^2s)[45]
- A = Area of contaminated zone (228,000 m^2)
- H_{mix} = Height of interest for uniform mixing (1 m for plants, 2 m for adults)
- U = Average wind speed (3.4 m/s) [Gleckler, et al, 1995]

4.4.1.3 Offsite Radon Contribution

Contributions to a resident at the LLRW disposal site boundary can only occur via gaseous diffusion of radon emanating onsite. The gaseous concentration offsite is determined by using the onsite surface flux estimate, which varies depending upon the cover material and layers. The flux is then multiplied by the area of the assumed contamination. For the gaseous emitters, this is the 228,000-square meter area of the LLRW disposal site. This provides a total LLRW disposal site release rate. This value is then multiplied by the dispersion coefficient for a contaminant at a specific offsite distance [US Ecology, 1996]. The maximum offsite distance is east-southeast of the LLRW disposal site. The estimates are calculated for the maximum predicted location. The formula for the calculation is as follows:

<u>Equation 14</u>

$$C_a = RadonFlux * Area_{site} * \frac{\chi}{Q} * \frac{1}{1{,}000}$$

Where:

- C_a = Air concentration offsite (pCi/l)
- Radon Flux = ground level emission rate (pCi/m^2*s)
- $Area_{site}$ = Area of trenches (m^2)
- X = The offsite air concentration at the location of interest (pCi/m^3)
- Q = product of the radon flux and the LLRW disposal site area (pCi/s)
- 1/1,000 = converts air concentration from m^3 to liters

4.4.2 Carbon 14

Carbon 14 is modeled separately from other radionuclides, due to the ever-present nature of carbon in the environment. Carbon 14 presents only an internal risk to humans, as the energy of the beta particle is too low to cause a concern for external exposure. For the carbon 14 modeling, it is assumed that equilibrium exists between the soil, plants, and humans. Due to the dry soil conditions at the LLRW disposal site,

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[45] The flux is based upon a homogenous carbon 14 source term. The realistic flux estimate is used for this analysis and is itself conservative, due to the assumptions made in determining the biodegradable portion.

carbon 14 was modeled as being released solely as a gas (as opposed to partially infiltrating to the groundwater). It is possible for carbon 14, assumed to exist after biodegradation as 50% carbon dioxide (and 50% methane), to increasingly be retained in the unsaturated soil column due to the greater moisture content for the higher infiltration estimates. Any potential movement of the carbonate stored in the soil column toward groundwater is limited by equilibrium reactions, depending upon pH and the concentration of calcium carbonate in the soil column. Although such movement toward the groundwater may exist, it would only be a fraction of the total carbon released to the air and would be limited by the total carbon remaining in the waste.

One of the major difficulties in estimating the dose from carbon 14 is determining the portion of the source volume that is available for biodegradation. Once the source term has been established, the carbon 14 flux emanating through the cover must be estimated. Dr. Man-Sung Yim calculated these initial portions of the dose calculation at North Carolina State University [Yim, 1997]. To summarize Dr. Yim's report:

- Approximately 55% of the total carbon 14 inventory is assumed to be biodegradable
- The predicted surface flux at the end of the institutional control period is 6.4×10^{-6} Ci/m^2y for the realistic estimate, and 10.7×10^{-6} Ci/m^2y for the conservative case[46]
- The difference between the two flux estimates results from the assumption that all of the organic materials are assumed to be biodegradable, regardless of chemical form (conservative case), whereas the expected chemical form of carbon 14 in various waste streams is taken into account for the biodegradability estimation in the realistic case

The surface flux estimate can then be utilized to determine an ambient air concentration using the following formula [Yu, et al, 1993]:

<u>Equation 15</u>

$$C_{C-14inair} = \frac{\left\{0.5 * EVSN * \sqrt{A}\ \right\}}{\left\{\ H_{mix} * U\ \right\}}$$

Where:

- $C_{C\text{-}14\ in\ air}$ = Average concentration of carbon 14 in air over a contaminated area (pCi/m^3)
- 0.5 = Default time fraction wind is blowing toward individual (dimensionless)
- EVSN = Carbon 14 flux (pCi/m^2s)[47] [Yim, 1997]
- A = Area of contaminated zone (228,000 m^2)
- H_{mix} = Height of interest for uniform mixing (1 m for plants, 2 m for adults)

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[46] These estimates are corrected for the upward revision of the source term from the 3670 curies used in the original calculations to the 5,247 curies used in the final calculations. The 5,247 curies accounts for the projected disposal of C-14 through the year 2056.

[47] The flux is based upon a homogenous carbon 14 source term. The realistic flux estimate is used for this analysis and is itself conservative, due to the assumptions made in determining the biodegradable portion.

- U = Average wind speed (3.4 m/s) [Gleckler, et al, 1995]

The flux estimate is a total carbon 14 flux per year; however, a portion of this carbon 14 is in the form of methane (CH_4) and unavailable for photosynthesis. The fraction of the carbon 14 that is methane is assumed to be 50%[48] [Tchobanoglous, et al, 1993].

The next step is to calculate the concentration in plants due to the concentration in air and soil [Yu, 1993].

Equation 16

$$C_{C-14,v} = C_{c,v} * \left\{ \left\{ F_a * \frac{C_{C-14,a}}{C_{C,a}} \right\} + \left\{ F_s * \frac{S_{C-14}}{S_C} \right\} \right\}$$

Where:

- $C_{C\text{-}14,v}$ = Concentration of carbon 14 in plants (pCi/kg)
- $C_{C,v}$ = Fraction of stable carbon in plants[49] (0.1)
- F_a = Fraction of carbon in plants derived from carbon in air (0.98) [Yu, 1993]
- F_s = Fraction of carbon in plants derived from carbon in soil (0.02) [Yu, 1993]
- $C_{C,a}$ = Concentration of stable carbon in air ($1.6\text{x}10^{-4}$ kg/m^3) [Yu, et al, 1993]
- $S_{C\text{-}14}$ = Concentration of carbon 14 in soil (pCi/kg)
- S_C = Fraction of soil that is stable carbon (0.03) [Yu, et al, 1993]

The contaminated zone where the material is buried is located approximately five meters beneath the surface for all closure alternatives, with the exception of the Site Soils alternative. Effective plant root depths are significantly less than the depth of contamination; as a result, the soil-to-plant pathway is not a contributor to dose. The resulting contamination is due solely to intake of carbon during photosynthesis. As the flux is assumed constant over time, this plant concentration is an assumed equilibrium value.

The final step in the estimate of the dose contribution to an onsite individual is to calculate the total carbon 14 intake on an annual basis. Using the NRC-recommended consumption values for the general population [Kennedy and Strenge, 1992] and the EPA estimates for locally grown products [U.S. EPA, 1991], the estimated consumption of fruit consumption is 13.8 kg/year, of leafy vegetables is 4.4 kg/year,[50] and of other

[48] Low-level radioactive waste landfills have been shown to be chemically similar to sanitary landfills [Husain, et al, 1979]. Although the rate of production of gases is small when compared to sanitary landfills [Kunz, 1982], the composition of the gases, over time, is expected to be similar to sanitary landfills.
[49] Take the carbon in vegetation of 0.45 kg C/kg dry [Napier, et al, 1988] and multiply it by the dry-to-wet weight conversion factors [Kennedy and Strenge, 1992] (0.18, 0.25, and 0.20 for fruit, other vegetables, and leafy vegetables, respectively) weighted by the respective consumption of homegrown produce recommended by the EPA [U.S. EPA, 1991].
[50] The EPA does not provide a separate value for the intake of leafy vegetables. The leafy vegetable consumption rate is therefore calculated using the ratio of the leafy vegetable fraction recommended by Kennedy [Kennedy and Strenge, 1992], multiplied by the consumption rate of vegetables recommended by the EPA.

vegetables is 20.4 kg/year, from which a total intake of 38.6 kg/year is obtained. This results in a combined annual carbon 14 intake of 3.8 kg per year, assuming that all consumed carbon is in the form of carbon 14.

For the Native American, using the recommended consumption values [Harris and Harper, 1997] and estimates of locally grown products, the estimated consumption of local fruit is 52.3 kg, of leafy vegetables is 40.2 kg, and of other vegetables is 37.4 kg. This results in a combined annual carbon 14 intake of 12 kg per year, assuming all consumed carbon is in the form of carbon 14.

Using the dose conversion factor of 5.64×10^{-10} Sv/Bq [Eckerman, et al, 1988], the resulting formula to estimate the dose is:

<u>Equation 17</u>

$$Dose(mrem/y) = \frac{C_{C14,v}}{g} * \frac{carbonIntake}{y} * \frac{Bq}{27\,pCi} * \frac{5.64E-10Sv}{Bq} * \frac{E+05mrem}{Sv}$$

Individuals residing within the area in which the carbon 14 flux is emanating will also receive a dose contribution as a result of inhalation. However, due to the low air concentration and an even lower dose conversion factor (6.2×10^{-12} Sv/Bq), the resulting dose contribution is approximately 180 times lower than the plant ingestion contribution.

4.4.2.1 Offsite Impact from Carbon 14

The calculations to the offsite individual from carbon 14 are performed exactly like the method provided in Section 4.4.1.3. The only parameter that changes is the carbon 14 flux estimate.

4.4.3 Tritium Analysis

Tritium analysis, similar to carbon 14 analysis, is performed separately from other radionuclides due to the ever-present nature of hydrogen in the environment. Tritium presents only an internal hazard, due to the extremely weak beta emission of the radionuclide.

Based upon the potential for offsite impact during the institutional control period, the calculation of the expected dose to an offsite individual at the maximum downwind location is as follows:

The tritium surface flux is estimated using the RADON computer code [USNRC, 1989a]. For the 2056 closure date, the predicted surface flux is 0.5 pCi/m^{2}s. Using the formula provided in Section 4.4.1.3, with a dispersion coefficient of 2.8×10^{-5} for a location 330m ESE (from the center of the LLRW disposal site), the estimated ambient concentration is 0.0029 pCi/l. The NCRP dose factor for tritium at equilibrium is 9.5×10^{-5} mrem/year per pCi/L [NCRP, 1983]. Applying the equilibrium dose factor for tritium in the environment, a predicted dose of 3×10^{-7} mrem/year is obtained. The dose factor assumes uniform concentrations in air, groundwater, plants, and animals.

Similarly, the surface flux estimate can then be utilized to determine an ambient air concentration onsite, using the following formula [Yu, et al, 1993]:

Equation 18

$$C_{h-3inair} = \frac{\{0.5 * EVSN * \sqrt{A}\ \}}{\{\ H_{mix} * U\ \}}$$

Where:

- $C_{H\text{-}3\ in\ air}$ = Average concentration of carbon 14 in air over a contaminated area (pCi/m^3)
- 0.5 = Default time fraction wind is blowing toward individual (dimensionless)
- EVSN = Tritium flux (pCi/m^2*s)[51] [Yim, 1997]
- A = Area of contaminated zone (228,000 m^2)
- H_{mix} = Height of interest for uniform mixing (1 m for plants, 2 m for adults)
- U = Average wind speed (3.4 m/s) [Gleckler, et al, 1995]

For example, using the year 2000 as the proposed closure date, with institutional control lapsing in the year 2107 (it takes seven years to close the LLRW disposal site), the estimated 1,100 curies of tritium remaining will result in a surface flux of 0.02 pCi/m^2*s, resulting in an onsite air concentration of 0.0011 pCi/l. The calculated dose is therefore $9.5x10^{-5}$ * 0.0011, and equals $1x10^{-7}$ mrem/year.

As the predicted impacts from tritium, onsite or off, are too small to warrant consideration in the alternatives, further estimates of tritium impact to the air, offsite or onsite, are not provided in the results.

4.5 Food

Food contamination results from contamination in one or all of the three primary exposure routes: air, water, and soil. Food ingestion is included as its own pathway in order to clearly provide its impact on the predicted dose. The food analysis is divided into two categories: impacts that result from the ingestion of fruit and vegetables, and impacts that result from the ingestion of meat and dairy products.

4.5.1 Ingestion of Fruit and Vegetable Products

The analysis considers two mechanisms by which food contamination can occur: through irrigation, or through the uncovering of waste by the intruder. The analysis from the direct removal of waste and subsequent use for crops simplifies the analysis presented for estimating the impact from irrigation, as the soil concentration is at a

[51] The flux is based upon a homogenous carbon 14 source term. The realistic flux estimate is used for this analysis and is itself conservative, due to the assumptions made in determining the biodegradable portion.

maximum initially. Soil contaminated by irrigation must build up in concentration over time.

4.5.1.1 Ingestion of Fruit and Vegetable Products Contaminated by Overhead Irrigation Spray

The calculation of the concentration on the plant from overhead irrigation involves two separate stages. The first stage is determining the amount retained on plants after being sprayed by irrigation water. The second stage is the calculation of the additional contamination as a result of root uptake and resuspension of contaminated soil onto the plant. The two stages are then added to obtain a combined contaminant concentration on edible plant surfaces. The plant concentration is then consumed according to each plant type, and a dose conversion factor is applied to the total intake to calculate the final dose from ingestion of produce.

In order to calculate the concentration on the plant following the initial deposition, an estimate must first be made of the deposition rate [Kennedy and Strenge, 1992]:

<u>Equation 19</u>

$$R = \left\{ IR * r_v * T_v * C_w \right\} / Y_v$$

Where:

- R = Average deposition rate to edible parts of plant from application of irrigation water (pCi/kg*d)
- IR = Application rate of irrigation water (L/m^2*d)
- r_v = Fraction of initial deposition retained on plant (dimensionless)
- T_v = Translocation factor for transfer of radionuclides from plant surfaces to edible parts (dimensionless)
- C_w = Average concentration in irrigation water (assumed constant) (pCi/L)
- Y_v = Plant yield (kg wet weight/m^2)

Following the estimate of the deposition rate, a calculation of the contribution from direction deposition is an ordinary, first order, linear differential equation. The solution to the equation is as follows:

<u>Equation 20</u>

$$C_{plant} = R / \lambda \left\{ 1 - e^{-\lambda t} \right\}$$

Where:

- C_{plant} = The radionuclide concentration in the plant from deposition onto plant surfaces (pCi/kg)
- λ = Effective weathering and decay constant (d-1)
- t = growth period for plant (d)

For simplicity, losses from radiological decay during the holdup period[52] and consumption period are neglected. This conservative assumption has no significant impact on the dose contribution, as the radionuclides of interest have long half-lives.

The second stage of the calculation is the estimate of the concentration in plants resulting from resuspension and root uptake. In order to estimate this contribution, the average soil concentration must first be calculated. This linear differential equation is similar to equation 20, with the exception of the loss term.

The loss of contaminants from soil is due to leaching by infiltrating water. This infiltration rate is different from the estimated infiltration rate of the buried waste of the LLRW disposal site, as the area of interest for plants (in our calculations) is the first 15 centimeters of soil (and not the five meters of soil needed to get to the buried waste). As a result of this decrease in the depth of interest (compared to the contaminated zone), infiltration rates may be significantly higher than the buried waste contaminated zone, yet not impact deeper depths, due to the large percentage of evaporation losses that are estimated to occur in the top 0.5 m of soil.[53]

Equations 21 through 24 are necessary in order to determine the loss of contaminants due to leaching [Yu, et al, 1993]. Equation 21 utilizes a combination of site-specific and default data to obtain an estimated infiltration rate.

<u>Equation 21</u>

$$I = \{1 - C_e\}\{\{1 - C_r\}P_r + I_{rr}\}$$

Where:

- I = Infiltration rate (m/year)
- C_e = Evapotranspiration coefficient (dimensionless)
- C_r = Runoff coefficient (dimensionless)
- P_r = Precipitation rate (m/year)
- I_{rr} = Irrigation rate (m/year)

In order to determine the retardation factor, it is first necessary to calculate the saturation ratio in equation 22.

<u>Equation 22</u>

$$R_s = \{I / K_{sat}\}^{1/\{2b+3\}}$$

[52] The holdup period is the time between produce harvest and consumption.
[53] Basically, the infiltration rate should be greater for the surface soil than soil at a greater depth.

Where:

- R_s = Saturation Ratio
- K_{sat} = Hydraulic conductivity (m/year)
- b = soil specific exponential parameter [Yu, et al, 1993][54] (dimensionless)

The retardation factor in equation 23 [Yu, et al, 1993] is the ratio of the pore water velocity to the radionuclide transport velocity.

<u>Equation 23</u>

$$R_d = 1 + \{\rho_b * K_d\} / \{p_t * R_s\}$$

Where:

- R_d = Retardation factor (dimensionless)
- ρ_b = Soil density (g/cm^3)
- p_t = Soil porosity (dimensionless)
- K_d = Distribution coefficient (cm^3/g)

Equation 24 [Yu, 1993] is used to obtain a time independent estimate of the leach rate in the top 15 centimeters of soil as a result of the application of irrigation water and local precipitation.

<u>Equation 24</u>

$$L = I / \{\theta * T * R_d\}$$

Where:

- L = Leach rate (y^{-1})
- θ = Volumetric water content (dimensionless)
- T = Thickness of contaminated zone (m)

Having obtained the information necessary to calculate the loss term in the soil, equation 25 [Kennedy and Strenge, 1992] calculates the radionuclide deposition rate onto the soil.

<u>Equation 25</u>

$$R_{soil} = \{C_w * IR\} / P_s$$

Where:

- R_{soil} = Average deposition rate onto soil (pCi/kg*d)
- P_s = Aerial soil density (kg/m^2)

[54] The soil-specific b parameter is an empirical parameter used to evaluate the saturation ratio of the soil.

The final concentration at the end of the growing period is shown in equation 26. In order to account for continued deposition over time, equation 26 was modified by taking the time for plant growth to infinity. The resulting equilibrium concentration is simply the deposition rate divided by the leach rate.

<u>Equation 26</u>

$$C_{soil} = R_{soil} /(L * 365) * \{1 - e^{-Lt}\}$$

Where:

- C_{soil} = Radionuclide soil concentration at end of growing period (pCi/kg)

Finally, equation 27 calculates the concentration in the plant due to uptake and resuspension [Kennedy and Strenge, 1992].

<u>Equation 27</u>

$$C_{plant} = \{ML + B\} * W_{d-w} * C_{soil}$$

Where:

- C_{plant} = Radionuclide concentration in plant (pCi/kg)
- ML = Mass loading factor for resuspension of soil to edible portions of plant (dry weight)
- B = Concentration factor for uptake of soil to plant (dry weight basis)
- W_{d-w} = Conversion factor for plants from dry weight to wet weight

The total contaminant concentration is the sum of equations 20 and 27. The formula is as follows:

<u>Equation 28</u>

$$Dose_{plants} = \frac{C_{plants}}{27} * Q_{plants} * DCF * F * 10^{8}$$

Where:

- $Dose_{plants}$ = Committed effective dose from ingesting contaminated vegetation (mrem/year)
- C_{plants} = Contaminant concentration in plants (pCi/g)
- Q_{plants} = Intake rate of vegetation (kg/year)
- DCF = 50 year committed effective dose conversion factor for ingestion of contaminants (Sv/Bq)
- F = Fraction of contaminated material that is grown
- 10,000,000 = Converts Sieverts (Sv) to mrem and grams to kilograms
- 27 = Converts pCi to Bq

The fraction of contaminated material that is assumed grown in a particular location is obtained from the EPA [U.S. EPA 1991]. To summarize, in a rural setting for the general population, the EPA assumes that 40% of all vegetables and 30% of all fruits are grown by the individuals.[55] The basis for the EPA-recommended fractions is that while farm families can grow a large number of fruits and vegetables, it is unlikely that the individual (or family) could grow a sufficient variety to meet dietary needs and tastes.[56] For the Native American, it is assumed that 62% of the fruit and vegetables are grown locally [Harris and Harper, 1997].

4.5.1.2 Ingestion of Fruit and Vegetable Products Contaminated by Direct Removal of Contaminated Waste

The calculation of the onsite concentration in fruits and vegetables from direct contact with contaminated waste parallels the discussion of the analysis performed for the irrigation pathway, with a few exceptions. First, the soil concentration for the contaminated soil uncovered (from the drilling of a well) is the result of a single deposition event, as opposed to deposition over time in the irrigation pathway analysis. The contaminant concentration for the well material analysis is a maximum when initially deposited, and is reduced over time, due to leaching into the soil and radioactive decay. By comparison, the contaminant concentration for a particular contaminant in the irrigation pathway reaches an equilibrium value over a period of time, due to continued deposition, year after year. This equilibrium contaminant concentration for the irrigation pathway would remain so until irrigation activities cease. Only then would the irrigation pathway contaminant concentration resemble the reduction in contaminant concentration for the well volume material. Second, the plants in the irrigation pathway receive a portion of their contamination from direct deposition of the irrigation water (overhead spray is assumed). For the well volume material, the only pathway is root uptake and resuspension to the plants, as opposed to direct deposition as well (for irrigated plants).[57]

4.5.2 Ingestion of Meat and Dairy Products

The following pathways are considered in the analysis of animal ingestion:

- Ingestion of beef cattle
- Ingestion of milk (dairy cattle)
- Ingestion of poultry
- Ingestion of eggs

[55] Due to the limited size of area assumed, grains are not assumed to be locally grown. There is also little evidence of individuals growing grain for personal and not commercial use.
[56] The EPA-recommended fraction is not based upon the size of land. For comparison, the NRC [U.S. NRC, 1977] assumes that an individual's entire diet is raised on a 10,000 m² site. NUREG/CR 3620 [Napier. et al, 1984] further defined the fractional breakout, roughly estimating that approximately 75% of the family's needs could be produced with land the size of the 2,500 m² plot. Based upon this information and the inability of a family to produce a sufficient variety of fruits and vegetables, the EPA values appear appropriate and sufficiently conservative.
[57] The 1,500 m² contaminated soil area for the well volume analysis is a portion of the same area that is used for the irrigation pathway. Although the analysis is performed separately, the results are summed, as the 1,500-m² area is expected to also contain contamination as a result of contaminated irrigation water.

The animals, in turn, are exposed to contamination via a number of mechanisms. The mechanisms considered are:

- Direct Ingestion of Well Water by Animals
- Animal Ingestion of Plants Contaminated Directly from Irrigation Spray and from Root Uptake and Resuspension of Soil Contamination[58]
- Direct Ingestion of Contaminated Soil

4.5.2.1 Direct Ingestion of Well Water by Animals

The computer code GWSCREEN [Rood, 1994] estimates the contaminant concentration in the groundwater. The groundwater concentration output is then directly used as the concentration in the well water that the animals drink. A transfer factor is then utilized to estimate the contaminant concentration in the edible portion of the animal as a result of ingesting contaminated well water. The formula for estimating the concentration in the animal product is as follows:

Equation 29

$$C_{animals,water} = C_W * Q_w * TF$$

Where:

- $C_{animals,\ water}$ = Concentration in animals due to water intake (pCi/kg)
- C_w = Groundwater concentration (pCi/l)
- Q_w = Intake rate of water by animals (l/d)
- TF = Transfer factor that takes into account the concentration in the edible portion of the animal to the concentration in the water (pCi/kg/pCi/d)

The contaminant intake amounts are located in the supporting documentation for this analysis [Thatcher, et al, 1998].

4.5.2.2 Ingestion of Plants Contaminated Directly from Irrigation Spray and from Root Uptake and Resuspension of Soil Contamination

The plants irrigated for the animals include fresh forage, stored hay, and stored grain. The specific intake of each fraction for an animal generally depends upon the season. However, an average ingestion amount for each animal per food group is utilized for these calculations [Kennedy and Strenge, 1992]. Specific values for each parameter are located in the supporting documentation for this analysis [Thatcher, 1998]. The methodology for the animal ingestion pathway closely follows that of direct plant ingestion (by humans). The main difference is that humans consume plant material at the end of the growing season, whereas animals consume the plants continuously.

[58] Animal contamination as a result of direct contamination of waste is not considered, due to the limited size of the material removed.

The calculation of the concentration on the plant involves two separate stages. The first stage is the calculation of the contamination on the plant as a result of directly deposited material. The second stage is the calculation of the additional contamination as a result of root uptake and resuspension. The two stages are then added to obtain a combined contaminant concentration on edible plant surfaces.

The first stage in the calculation of the concentration of the plant is an estimate of the deposition rate. The formula for the deposition rate [Kennedy and Strenge, 1992] is:

<u>Equation 30</u>

$$R = \frac{I_{rr} * r_v * T_v * C_w}{Y_v}$$

Where:

- R = Average deposition rate to edible parts of plant from application of irrigation water (pCi/kg*d)
- I_{rr} = Application rate of irrigation water (L/m^2*d)
- r_v = Fraction of initial deposition retained on plant (dimensionless)
- T_v = Translocation factor for transfer of radionuclides from plant surfaces to edible parts (dimensionless)
- C_w = Average concentration in irrigation water (assumed constant) (pCi/l)
- Y_v = Plant yield (kg wet weight/m^2)

Following the estimate of the deposition rate, a calculation of the contribution from direction deposition is a first-order linear differential equation. Equation 31 applies to stored grain and hay, as the formula takes into account the accumulation of contamination over the entire growing season. The solution to the equation is as follows:

<u>Equation 31</u>

$$C_{plant,stored} = R / \lambda \left\{1 - e^{-\lambda t}\right\}$$

Where:

- $C_{plant,\ stored}$ = The radionuclide concentration in the plant from deposition onto plant surfaces (pCi/kg)
- λ = Effective weathering and decay constant (d-1)
- t = growth period for plant (d)

For simplicity, losses during the holdup period[59] and consumption period are neglected. This conservative assumption has no significant impact on the dose contribution, as the three radionuclides of interest have long half-lives.

[59] The holdup period is the time between produce harvest and consumption.

The calculation of the contribution from direct deposition for grasses (fresh forage) takes into account the fact that animals ingest the contaminated grass during the entire growing period. As a result, the amount of contamination ingested is an average of the entire growing period.[60] The solution for this equation is as follows:

<u>Equation 32</u>

$$C_{plant,direct,avg} = \frac{(\frac{R * t}{\lambda}) - (\frac{R}{\lambda^2} * (1 - E^{(-\lambda * t)}))}{t}$$

Where:

- $C_{plant,direct,\ avg.}$ = Average plant concentration for fresh forage (pCi/kg)

The second stage of the calculation is the estimate of the concentration in plants resulting from resuspension and root uptake. In order to estimate this contribution, the average soil concentration must first be calculated. This linear differential equation is similar to equation 31, with the exception of the loss term.

Prior to calculating the average soil concentration, the loss due to leaching must be estimated. The loss of contaminants from soil is due to leaching by infiltrating water. This infiltration rate is different from the estimated infiltration rate of the buried waste of the LLRW disposal site, as the area of interest for plants is the first 15 centimeters of soil. As a result of this decrease in the depth of interest (compared to the contaminated zone), infiltration rates may be significantly different than those of the deeper wastes due to increased evaporation losses and differences in soil density.

Equations 21 through 24 are used to determine the loss of contaminants due to leaching [Yu, et al, 1993]. Equation 33 [Kennedy and Strenge, 1992] calculates the radionuclide deposition rate onto the soil.

<u>Equation 33</u>

$$R_{soil} = \frac{C_w * I_{rr}}{P_s}$$

Where:

- R_{soil} = Average deposition rate onto soil (pCi/kg*d)
- P_s = Aerial soil density (kg/m^2)

The final concentration at the end of the growing period is shown in equation 34. In order to account for continued deposition over time, equation 34 was modified by taking the time for plant growth to infinity. The resulting equilibrium concentration is simply the deposition rate divided by the leach rate.

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[60] Equation 15 is derived by integrating equation 14 with respect to time, to yield an average value.

Equation 34

$$C_{soil} = \frac{R_{soil}}{L * \left\{1 - e^{-Lt}\right\}}$$

Where:

- C_{soil} = Radionuclide soil concentration at end of growing period (pCi/kg)

Finally, equation 35 calculates the concentration in the plant due to uptake and resuspension [Kennedy and Strenge, 1992]:

Equation 35

$$C_{plant,uptake+resuspension} = \left\{ML + B\right\} * W_{d-w} * C_{soil}$$

Where:

- C_{plant} = Radionuclide plant concentration (pCi/kg)
- ML = Mass loading factor for resuspension of soil to edible portions of plant
- B = Concentration factor for uptake of soil to plant (dry weight basis)
- $W_{d\text{-}w}$ = Conversion factor for plants from dry weight to wet weight

Once the estimated animal feed concentrations have been calculated (equations 31, 32, and 35), the concentration in the edible portion of the animal may then be estimated. The formula for estimating the contribution in the animal due to deposition and uptake from fresh forage is:

Equation 36

$$C_{Animals,forage} = (TF * Q_{a,forage} * f_w) * (C_{plant,direct} + C_{plant,uptake+resuspension})$$

Where:

- $C_{Animals,\ forage}$ = Concentration in animals as a result of ingesting contaminated fresh forage
- TF = Transfer factor relating the concentration in the edible portion of the animal to the intake concentration (pCi/kg/pCi/d)
- $Q_{a,\ forage}$ = Consumption rate of fresh forage by animals (Kg/d)
- f_w= Fraction of forage that is contaminated (unitless, 1)

The formula for estimating the concentration in the edible portion of the animal as a result of ingesting stored feed is as follows:

Equation 37

$$C_{Animal,storedfeed} = TF * ((f_w * C_{grain} * Q_{a,grain}) + (f_w * C_{storedhay} * Q_{a,storedhay}))$$

Where:

- $C_{animal, stored feed}$ = Concentration in animals as a result of ingesting stored feed (pCi/kg)
- C_{grain} = Concentration in the grain (pCi/kg)
- $C_{stored hay}$ = Concentration in the stored hay (pCi/kg)
- $Q_{a, grain}$ = Consumption rate of grain by the animal (kg/d)
- $Q_{a, stored hay}$ = Consumption rate of stored hay by the animal (kg/d)

4.5.2.3 Ingestion of Soil by Animals

Animals inadvertently ingest soil in the process of consuming feed. For this process, the animals are presumed to only ingest soil while consuming fresh forage. The amount of soil ingested is taken to be a fraction of the amount of forage consumed. The formula for the concentration in the edible portion of the animal as a result of ingesting contaminated soil is [Kennedy and Strenge, 1992]:

Equation 38

$$C_{Animals,soil} = TF * f_w * Q_{a,forage} * IF * W_{D-W} * C_{Soil,avg}$$

Where:

- $C_{animals, soil}$ = Concentration in animals due to the ingestion of soil (pCi/kg)
- $Q_{a, forage}$ = Consumption rate of vegetation by animals (kg/d)
- IF = Intake fraction of soil (unitless)
- W_{D-W} = Dry to wet weight conversion factor (unitless)
- $C_{soil, ave}$= Average contaminant concentration in soil (pCi/kg)

4.5.2.4 Overall Contribution from the Animal Pathway

Equations 29, 36, 37, and 38 are combined to obtain an overall contribution for the animal pathway from the ingestion of groundwater well, plants, and soil. The resulting estimated dose is:[61]

Equation 39

$$D^{Humans}_{Animalpathway} = DCF * 365d / y * Q_{h,animalproduct} * \frac{10^5}{27} * (C^{Animals}_{Water} + C^{Animals}_{stored} + C^{Animals}_{forage} + C^{Animals}_{Soil})$$

Where:

- D^{humans} = Dose to humans from the animal ingestion pathway (mrem/year)
- DCF = Dose conversion factor (Sv/Bq)
- $\frac{10^5}{27}$ = Factors to convert Sv to mrem and pCi to Bq

[61] Note that the equation is simplified by assuming that no decay occurs during the period of time between harvest and consumption. This assumption is valid, as the radionuclides of interest for the groundwater pathway are very long lived.

27

- $Q_{h, animal\ product}$ = Consumption rate of specific animal product by humans (kg/d)

4.6 Surface Water

Surface water on or in the near vicinity of the LLRW disposal site does not exist. Scenarios involving surface water are therefore not used for this analysis.

5.0 Estimated Offsite Dose

The Proposed Action and each alternative have been analyzed for the Rural Resident and Native American scenarios to determine offsite dose and risk. Methods discussed in Section 4 were used for the analysis. The results of the analyses are presented in terms of the maximum expected dose and incremental lifetime cancer risk. The following bullets are a brief summary of the conditions that apply to the analyses; further details can be located in Sections 3 and 4:

- Groundwater-related contributions include drinking water ingestion, food ingestion, and other related pathways such as sweat lodge inhalation for Native Americans.
- All groundwater results represent the maximum downgradient location (i.e., the maximum concentration for onsite or offsite).
- Radionuclides modeled for groundwater dose are H-3, Tc-99, Cl-36, I-129, U-235, and U-238 (see the Groundwater Analysis report in the EIS for further discussion on the derivation of the contaminant concentration).
- All results other than groundwater relate to the diffusion or dispersion of contaminated soils or gases from onsite sources.
- All calculations assumed the loss of institutional controls at 107 years.[62]
- The results tables contain a segregation at 500 years. This time break is a result of the increased contribution from sealed radium sources that are assumed to contribute to dose after 500 years.
- Results are only calculated for radionuclides with travel times less than 10,000 years.
- Total dose is calculated by the sum of groundwater-related activities and diffusion of gases and dust from onsite. Dose is then multiplied by the assumed years of exposure and a probability of fatal cancer coefficient [ICRP, 1990]. The probability coefficient is .0005/rem (committed effective dose).
- Dose conversion factors from ICRP 72 [ICRP, 1995] are used for this report, as it is the only reference that segregates the dose conversion factors based upon age, thereby allowing for a more accurate assessment of the potential exposure to a child.
- Spreadsheet results containing detailed calculations are located in supporting documentation [Thatcher, et al, 1998].

[62] 107 years represent 100 years of institutional controls and seven years of onsite “active” maintenance.

- To allow comparison, dose and risk are reported as two significant figures, which is not a reflection of accuracy. See Section 10 on uncertainty analysis for a discussion of the accuracy of the results.

In addition, as predicted transit times for the each radionuclide are sufficiently close for all of the alternatives considered (see the Groundwater analysis appendix for further discussion), and the differences in travel times between radionuclides are sufficiently great, the radionuclides are segregated into two groups. The first group includes technetium 99 and chlorine 36. The predicted time for the maximum concentration ranges from 700 years for the Site Soils cover to approximately 1,000 years for the enhanced covers and the Thick Homogeneous cover. The maximum concentration for the Proposed Cover and Filled Site cover for these two radionuclides is approximately 800 to 900 years.

In contrast, the second group includes iodine 129, uranium 238, and uranium 235.[63] The maximum concentration predicted for I-129 ranges from 8,000 years for the Site Soil cover to more than 10,000 years for the enhanced covers and the Thick Homogeneous cover. The maximum concentration for the Proposed Cover and Filled Site cover for I-129 is approximately 9,800 years. For all of the covers considered, uranium is not expected to reach a maximum concentration prior to 10,000 years. The uranium concentrations reported therefore represent the estimated concentration at 10,000 years.

The estimated dose from these two groups of radionuclides are not added together since the groundwater concentrations from the first group (Tc-99 and Cl-36) are at vanishingly small concentrations by the time Iodine peaks in the groundwater.

5.1 Proposed Action: Offsite Results

This section presents the results for the Proposed Action, as described in Table 1.   The groundwater analysis for the Proposed Action predicted an infiltration rate of 2 mm/year and a groundwater travel time of 900 years for Tc-99 and Cl-36. The predicted concentration from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution for the adult scenarios and is less than the Tc-99 and Cl-36 contribution for the child scenarios. Table 9 presents the results for the rural resident adult and child for all exposure pathways. Table 10 presents the results for the Native American adult and child.

[63] The contributions from uranium progeny in groundwater, including uranium 234, are sufficiently small at 10,000 years that they are not further considered in the dose analysis. The contribution from progeny is included in the uncertainty analysis section.

Table 9 Summary of Estimated Offsite Dose for the Proposed Action

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Rural Resident Adult (mrem/yr)*			Rural Resident Child (mrem/yr)*		
Groundwater Related	0.0	2.7	3.4	0.0	7.6	4.2
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	1.0	4.3	4.3	1.0	4.3	4.3
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.1	7.1	7.8	1.1	12.0	8.6

*mrem/yr peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 10 Summary of Estimated Offsite Dose for the Proposed Action

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Native American adult (mrem/yr)*			Native American Child (mrem/yr)*		
Groundwater Related	0.0	7.4	7.7	0.0	14	7.3
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	1.0	4.3	4.3	1.0	4.3	4.3
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.1	12	12	1.1	18.0	12

*mrem/yr peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 11 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 2,200 for the Native American child to one in 8,300 for the rural resident adult. It is important to point out that a majority of the risks included in Table 11 are not predicted to occur for several centuries into the future.

Table 11 Lifetime Risk from Radionuclide Exposure for the Proposed Action

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	7.8	30.0	0.2	5.0×10^{-04}	1.2×10^{-04}
Rural Resident Child*	12.0	30.0	0.3	5.0×10^{-04}	1.3×10^{-04}
Native American Adult	12.1	70.0	0.8	5.0×10^{-04}	4.2×10^{-04}
Native American Child*	18.0	70.0	0.9	5.0×10^{-04}	4.4×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult or 64 years as a Native American adult.

5.2 Filled Site: Offsite Results

This section presents the results for the Filled Site alternative, as described in Table 1. The difference between this alternative and the Proposed Action is the greater amount of source term. The cover design is the same as for the Proposed Action. The groundwater analysis for the Filled Site alternative predicted an infiltration rate of 2 mm/year and a groundwater travel time of 900 years for Tc-99 and Cl-36. The predicted concentration from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution for the adult scenarios and is less for the child scenarios. Table 12 presents the results for the rural resident adult and child for all exposure pathways. Table 13 presents the results of the projections for the Native American adult and child.

Table 12 Summary of Estimated Offsite Dose for the Filled Site Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Rural Resident Adult (mrem/yr)*			Rural Resident Child (mrem/yr)*		
Groundwater Related	0.0	3.1	3.9	0.0	8.8	4.9
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	1.7	7.6	7.6	1.7	7.6	7.6
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.8	11	12	1.8	16	13

*mrem/yr peak committed effective dose

**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.

NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 13 Summary of Estimated Offsite Dose for the Filled Site Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Native American Adult (mrem/yr)*			Native American Child (mrem/yr)*		
Groundwater Related	0.0	8.7	8.8	0.0	16	8.4
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.0	0.0	0.0
Diffusion of radon gas from onsite	1.7	7.6	7.6	1.7	7.6	7.6
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.8	16	17	1.8	23	16

*mrem/year peak committed effective dose

**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.

NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 14 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 1,700 for the Native American child to one in 5,800 for the rural resident adult. It is important to point out that a majority of the risks included in Table 14 are not predicted to occur for several centuries into the future.

Table 14 Lifetime Risk for the Filled Site Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	12	30.0	0.3	5.0×10^{-04}	1.7×10^{-04}
Rural Resident Child*	16	30.0	0.4	5.0×10^{-04}	1.9×10^{-04}
Native American Adult	17	70.0	1.2	5.0×10^{-04}	5.8×10^{-04}
Native American Child*	23	70.0	1.2	5.0×10^{-04}	6.0×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult and 64 years as a Native American adult.

5.3 Site Soils: Offsite Results

This section presents the results for the Site Soils alternative, as described in Table 1. The groundwater analysis for the Site Soils alternative predicted an infiltration rate of 20 mm/year. This is a significantly greater rate than the Proposed Action.[64] In this alternative, Tc-99 and Cl-36 are predicted to reach the groundwater in approximately 700 years. I-129 is estimated to reach the groundwater in approximately 8,000 years, whereas uranium is expected to peak at more than 10,000 years.

Table 15 presents the results for the rural resident adult and child for all exposure pathways. Table 16 presents the results for the Native American adult and child.

Table 15 Summary of the Estimated Offsite Dose for the Site Soils Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Rural Resident Adult (mrem/yr)***			**Rural Resident Child (mrem/yr)***		
Groundwater Related	0.0	3.2	4.8	0.0	9.3	5.9
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	3.5	15	15	3.5	15	15
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.6	19	20	3.6	25	21

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

[64] The increased infiltration of the Site Soils Alternative is due to a single layer of site soils used, with limited infiltration barriers.

Table 16 Summary of Estimated Offsite Dose for the Site Soils Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Native American adult (mrem/yr)***			**Native American Child (mrem/yr)***		
Groundwater Related	0.0	9.0	16	0.0	17	11
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	3.5	15	15	3.5	15	15
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	3.6	24	32	3.6	32.0	27

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 17 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 900 for the Native American adult and child, to one in 3,300 for the rural resident adult. It is important to point out that a majority of the risks included in Table 17 are not predicted to occur for several centuries into the future.

Table 17 Lifetime Risk for the Site Soils Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	20	30.0	0.6	5.0×10^{-04}	3.0×10^{-04}
Rural Resident Child*	25	30.0	0.6	5.0×10^{-04}	3.0×10^{-04}
Native American Adult	32	70.0	2.2	5.0×10^{-04}	1.1×10^{-03}
Native American Child*	32	70.0	2.2	5.0×10^{-04}	1.1×10^{-03}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult and 64 years as a Native American adult.

5.4 Thick Homogeneous Cover: Offsite Results

This section presents the results for the Thick Homogeneous Cover alternative, as described in Table 1. The Thick Homogeneous Cover has less estimated infiltration than the Proposed Action because of the higher evapotranspiration related to the top five-foot thick silt loam layer.[65] The groundwater analysis for the Thick Homogeneous Cover alternative predicted an infiltration rate of less than 0.5 mm\year and a groundwater travel time of 1,000 years for Tc-99 and Cl-36. The predicted concentration from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution

[65] The lower infiltration rate is due to two primary design improvements: (1) The greater silt fraction means that more water is held near the surface and is subsequently available for greater plant use. (2) The increased silt fraction means that the soil has a greater cation exchange capacity, which results in more nutrients available for the plants. Larger plants, due to the greater nutrients and available water, in turn use a greater amount of water, which leads to a lesser infiltration rate.

for the adult scenarios and is less than the Tc-99 and Cl-36 contribution for the child scenarios.

Table 18 presents the results for the rural resident adult and child for all exposure pathways. Table 19 presents the results for the Native American adult and child.

Table 18 Summary of Estimated Offsite Dose for the Thick Homogeneous Cover Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Rural Resident Adult (mrem/yr)***			**Rural Resident Child (mrem/yr)***		
Groundwater Related	0.0	1.5	1.6	0.0	4.3	2.0
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	1.6	6.9	6.9	1.6	6.9	6.9
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.7	8.5	8.6	1.7	11	9.0

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 19 Summary of Estimated Offsite Dose for the Thick Homogeneous Cover Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Native American Adult (mrem/yr)***			**Native American Child (mrem/yr)***		
Groundwater Related	0.0	4.1	3.5	0.0	7.6	3.5
Gaseous diffusion and resuspended material driven from onsite*	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	1.6	6.9	6.9	1.6	6.9	6.9
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.7	11	11	1.7	15	11

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 20 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 2,500 for the Native American child to less than one in 7,800 for the rural resident adult. It is important to point out that a majority of the risks included in Table 20 are not predicted to occur for several centuries into the future.

Table 20 Lifetime Risk for the Thick Homogeneous Cover

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	8.6	30	0.26	5.0×10^{-04}	1.3×10^{-04}
Rural Resident Child*	11	30	0.27	5.0×10^{-04}	1.4×10^{-04}
Native American Adult	11	70	0.78	5.0×10^{-04}	3.9×10^{-04}
Native American Child*	15	70	0.80	5.0×10^{-04}	4.0×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario and 24 years as a rural resident adult and 64 years as a Native American adult.

5.5 Enhanced Asphalt : Offsite Results

This section presents the results for the Enhanced Asphalt alternative, as described in Table 1. The Enhanced Asphalt alternative has a predicted infiltration rate of less than 0.5 mm/year and a groundwater travel time for Tc-99 and Cl-36 of 1,000 years. The predicted concentration from I-129 and uranium at 10,000 years slightly exceeds the Tc-99 and Cl-36 contribution for the adult scenarios, and is less than the Tc-99 and Cl-36 contribution for the child scenarios.

All the enhanced designs have essentially the same thick silt loam layer as the Thick Homogeneous Cover in addition to buried infiltration barriers. The reduced infiltration rate is based on the assumed effectiveness of the buried asphalt barrier. Please refer to Section 4.4 for a discussion of the relative performance assumptions for the enhanced barriers. Table 21 presents the results for the rural resident adult and child for all exposure pathways. Table 22 presents the results for the Native American adult and child.

Table 21 Summary of Estimated Offsite Dose for the Enhanced Asphalt Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Rural Resident Adult (mrem/yr)***			**Rural Resident Child (mrem/yr)***		
Groundwater Related	0.0	1.5	1.6	0.0	4.3	2.0
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	0.2	1.0	1.0	0.2	1.0	1.0
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.3	2.6	2.7	0.3	5.3	3.1

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 22 Summary of Estimated Offsite Dose for the Enhanced Asphalt Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Native American Adult (mrem/yr)***			**Native American Child (mrem/yr)***		
Groundwater Related	0.0	4.1	3.5	0.0	7.6	3.4
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	0.2	1.0	1.0	0.2	1.0	1.0
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.3	5.2	4.6	0.3	8.7	4.5

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 23 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 4,300 for the Native American child, to less than one in 25,000 for the rural resident adult. It is important to point out that a majority of the risks included in Table 23 are not predicted to occur for several centuries into the future.

Table 23 Lifetime Risk for the Enhanced Asphalt Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	2.7	30	0.08	5.0×10^{-04}	4.0×10^{-05}
Rural Resident Child*	5.3	30	0.10	5.0×10^{-04}	4.8×10^{-05}
Native American Adult	5.2	70	0.37	5.0×10^{-04}	1.8×10^{-04}
Native American Child*	8.7	70	0.46	5.0×10^{-04}	2.3×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult and 64 years as a Native American adult.

5.6 Enhanced Synthetic: Offsite Results

This section presents the results for the Enhanced Synthetic alternative, as described in Table 1. The groundwater analysis for the Enhanced Synthetic alternative predicted an infiltration rate of 0.5 mm/year and a groundwater travel time of 1,000 years for Tc-99 and Cl-36. The predicted concentration from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution for the adult scenarios and is less than the Tc-99 and Cl-36 contribution for the child scenarios.

The barrier for the Enhanced Synthetic alternative is a synthetic barrier. Please refer to Section 4.4 for a discussion of the relative performance assumptions for the enhanced barriers. Table 24 presents the results for the rural resident adult and child for all exposure pathways. Table 25 presents the results for the Native American adult and child.

Table 24 Summary of Estimated Offsite Dose for the Enhanced Synthetic Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Rural Resident Adult (mrem/yr)*			Rural Resident Child (mrem/yr)*		
Groundwater Related	0.0	1.5	1.6	0.0	4.3	2.0
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	1.7	7.4	7.4	1.7	7.4	7.4
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.8	8.9	9.0	1.8	12	9.4

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 25 Summary of Estimated Offsite Dose for the Enhanced Synthetic Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Native American Adult (mrem/yr)*			Native American Child (mrem/yr)*		
Groundwater Related	0.0	4.1	3.5	0.0	7.6	3.5
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	1.7	7.4	7.4	1.7	7.4	7.4
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.8	12	11	1.8	15	11

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 26 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 2,400 for the Native American adult and child, to less than one in 7,400 for the rural resident adult. It is important to point out that a majority of the risks included in Table 26 are not predicted to occur for several centuries into the future.

Table 26 Lifetime Risk for the Enhanced Synthetic Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	9.0	30	0.27	5.0×10^{-04}	1.4×10^{-04}
Rural Resident Child*	12	30	0.29	5.0×10^{-04}	1.4×10^{-04}
Native American Adult	12	70	0.81	5.0×10^{-04}	4.1×10^{-04}
Native American Child*	15	70	0.84	5.0×10^{-04}	4.2×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult and 64 years as a Native American adult.

5.7 Enhanced Bentonite Year 2056: Offsite Results

This section presents the results for the Enhanced Bentonite 2056 alternative, as described in Table 1. This cover utilizes a clay barrier in addition to the thick site soils. The groundwater analysis for the Enhanced Bentonite 2056 alternative predicted an infiltration rate of 0.5 mm/year and a groundwater travel time of 1,000 years for Tc-99 and Cl-36. The predicted concentration from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution for the adult scenarios and is less than the Tc-99 and Cl-36 contribution for the child scenarios. Table 27 presents the results for the rural resident adult and child for all exposure pathways. Table 28 presents the results for the Native American adult and child.

Table 27 Summary of Estimated Offsite Dose for the Enhanced Bentonite 2056 Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Rural Resident Adult (mrem/yr)***			**Rural Resident Child (mrem/yr)***		
Groundwater Related	0.0	1.5	1.6	0.0	4.3	2.0
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	0.9	4.1	4.1	0.9	4.1	4.1
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.0	5.7	5.8	1.0	8.4	6.2

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 28 Summary of Estimated Offsite Dose for the Enhanced Bentonite 2056 Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	**Native American Adult (mrem/yr)***			**Native American Child (mrem/yr)***		
Groundwater Related	0.0	4.1	3.5	0.0	7.6	3.5
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	0.9	4.1	4.1	0.9	4.1	4.1
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	1.0	8.3	7.7	1.0	12	7.6

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 29 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 3,300 for the Native American adult and child, to less than one in 12,000 for the rural resident adult. It is important to point out that a majority of the risks included in Table 29 are not predicted to occur for several centuries into the future.

Table 29 Lifetime Risk for the Enhanced Bentonite 2056 Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	5.8	30	0.17	5.0×10^{-04}	8.7×10^{-05}
Rural Resident Child*	8.4	30	0.19	5.0×10^{-04}	9.5×10^{-05}
Native American Adult	8.3	70	0.58	5.0×10^{-04}	2.9×10^{-04}
Native American Child*	12	70	0.61	5.0×10^{-04}	3.1×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario, and 24 years as a rural resident adult and 64 years as a Native American adult.

5.8 Enhanced Bentonite - Year 2000: Offsite Results

This section presents the results for the Enhanced Design C - Year 2000 alternative, as described in Table 1. This alternative is the same as Enhanced Bentonite 2056, but has less source term because the site is shut down in the year 2000. The groundwater analysis for the Enhanced Design Year 2000 alternative predicted an infiltration rate of 0.5 mm/year and a groundwater travel time of 1,000 years for Tc-99 and Cl-36. The predicted concentrations from I-129 and uranium at 10,000 years slightly exceed the Tc-99 and Cl-36 contribution for the adult scenarios, and are less than the Tc-99 and Cl-36 contribution for the child scenarios.

Table 30 presents the results for the rural resident adult and child for all exposure pathways. Table 31 presents the results for the Native American adult and child.

Table 30 Summary of the Estimated Offsite Dose for the Enhanced Bentonite - Year 2000 Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Rural Resident Adult (mrem/yr)*			Rural Resident Child (mrem/yr)*		
Groundwater Related	0.0	1.4	1.5	0.0	4.0	1.9
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.0	0.0
Diffusion of radon gas from onsite	0.6	2.8	2.8	0.6	2.8	2.8
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.7	4.3	4.4	0.7	6.9	4.8

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 31 Summary of Estimated Offsite Dose for the Enhanced Bentonite - Year 2000 Alternative

Time Frame (Years)	100-500	500-2,000	2,000-10,000	100-500	500-2,000	2,000-10,000
Scenario	Native American adult (mrem/yr)*			Native American Child (mrem/yr)*		
Groundwater Related	0.0	3.9	3.3	0.0	7.2	3.3
Gaseous diffusion and resuspended material driven from onsite**	0.1	0.1	0.1	0.1	0.1	0.1
Diffusion of radon gas from onsite	0.6	2.8	2.8	0.6	2.8	2.8
Diffusion of C-14 from onsite	0.0	0.0	0.0	0.0	0.0	0.0
Total	0.8	6.8	6.2	0.8	10	6.1

*mrem/year peak committed effective dose
**Assumes that an intruder is present onsite and has drilled a well, thereby causing an exposure potential.
NOTE: A significant amount of uncertainty exists for projections more than 1,000 years into the future.

Table 32 provides the results of the lifetime risks. The results of the analysis indicate projected risks (fatal cancer probability) in the range of one in 4,300 for the Native American adult and child, to less than one in 15,000 for the rural resident adult. It is important to point out that a majority of the risks included in Table 32 are not predicted to occur for several centuries into the future.

Table 32 Lifetime Risk for the Enhanced Bentonite - Year 2000 Alternative

Scenario	Yearly Dose (mrem)	Exposure Time (Years)	Combined Dose (rem)	Dose to Risk Conversion factor	Cancer Risk
Rural Resident Adult	4.4	30	0.13	5.0×10^{-04}	6.6×10^{-05}
Rural Resident Child*	6.9	30	0.15	5.0×10^{-04}	7.4×10^{-05}
Native American Adult	6.2	70	0.44	5.0×10^{-04}	2.2×10^{-04}
Native American Child*	10	70	0.46	5.0×10^{-04}	2.3×10^{-04}

*The lifetime risk for the child is calculated by assuming 6 years as a child for either scenario and 24 years as a rural resident adult and 64 years as a Native American adult.

5.9 Summary of Offsite Results

Table 33 summarizes the dose to the rural resident and Native American living offsite. The primary source for the offsite dose is from the groundwater with only a minor contribution from radon. Of all the alternatives analyzed, the Site Soils Cover stands out as providing the least protection from dose. Resulting doses for this cover range from 20 mrem/year for the rural resident adult, to 32 mrem/year for the Native American Child.

The Proposed Action and Filled Site Alternative have the same cover design and result in similar doses (see Table 33). These covers result in a significantly lower dose than the Site Soils Cover, but a somewhat higher dose than the Enhanced Designs. This is because the Cover Design for the Proposed Action and Filled Site Alternative are predicted to produce a lower evapotranspiration rate. The fact that the Filled Site Alternative and the Proposed Action have similar doses, shows that the increased source term from filling the LLRW disposal site to capacity has little measurable effect on the groundwater concentrations, and therefore on the offsite dose.

The Enhanced Designs and Thick Homogeneous Cover provide the best barrier to infiltration, and therefore the least dose. The higher performance of these covers is due to the thick silt layer providing higher evapotranspiration rates. Although the results do not show it, the Enhanced Designs would provide a better barrier to infiltration than the Thick Homogeneous Cover. This is because the Enhanced Designs have buried infiltration barriers providing a second level of protection. These buried barriers are not taken into account in the groundwater modeling (see the Groundwater report in this EIS for further discussion on the groundwater analysis).

There is essentially no difference in the offsite results between any of the Enhanced Designs or the Thick Homogeneous Cover. Any minor differences are due to radon. In the radon calculations; the secondary barriers were taken into account. The Enhanced Asphalt and Bentonite covers were assumed to maintain their effectiveness longer than the synthetic barrier in the Enhanced Synthetic cover. Since radon contributes little to the offsite dose, the difference in barriers is not too significant. The differences in expected dose due to variations in the closure date and/or radon can be more readily observed in the onsite results of Chapter 6.

The estimated dose for the child scenarios indicates a greater contribution from Tc-99 and Cl-36 than from the combined impact from I-129 and uranium. This is in contrast to the adult scenarios, which indicate that I-129 and uranium provide a greater contribution. The greater contribution from Tc-99 and Cl-36 is entirely due to the dose conversion factors (DCF) for those two radionuclides for children. The DCF for Tc-99 and Cl-36 is approximately 3.5 times greater than the adult DCF. For I-129, the DCF is only about 1.5 times greater for the child than for the adult. The contribution from uranium for either the adult or the child is sufficiently small that no sizable impact is observed.

Table 34 estimates the risk to the rural resident and Native American living offsite. By reviewing Table 33, one can see that the Native American is estimated to receive a greater dose than from living offsite in a similar location. The differences between the Native American as compared to the rural resident become greater when the dose is converted to risk. This greater risk difference is due solely to the use of a 70-year lifetime for the Native American, and a 30-year lifetime for the rural resident.

Differences in the dose and risk estimates when comparing the Native American results to the rural residential results can be attributed to a number of factors. Namely:

- Enhanced contribution as a result of an assumed increased consumption of fruits and vegetables, as well as a significantly greater assumed fraction grown locally (62.5% grown locally for the Native American, versus 30%-40% for the rural resident)
- Increased consumption of water to account for the additional water loss while using the sweat lodge
- Greater exposure due to the use of a sweat lodge
- Slight differences in the amount of meats and milk consumed as compared to the rural resident, and a greater assumed contaminant concentration for the organ meats

Table 33 Summary of Dose to Offsite Individuals (mrem/year)

Scenario	Alternatives							
	Proposed Action	Filled Site	Site Soils Cover	Thick Homogeneous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite - Year 2056	Enhanced Bentonite - Year 2000
Rural Resident Adult	8	12	20	9	2.7	9.0	5.8	4.4
Rural Resident Child	12	16	25	11	5.3	12	8.4	6.9
Native American Adult	12	16	32	11	5.2	12	8.3	6.2
Native American Child	18	23	32	15	8.7	15	12	10

Table 34 Summary of Risk to Offsite Individuals

(risk of fatal cancer per person)

Scenario	Alternatives							
	Proposed Action	Filled Site	Site Soils Cover	Thick Silt Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite - 2056	Enhanced Bentonite - Year 2000
Rural Resident Adult	1.2×10^{-04}	1.7×10^{-04}	3×10^{-04}	1.3×10^{-04}	4.0×10^{-05}	1.4×10^{-04}	8.7×10^{-05}	6.6×10^{-05}
Rural Resident Child	1.3×10^{-04}	1.9×10^{-04}	3×10^{-04}	1.4×10^{-04}	4.8×10^{-05}	1.4×10^{-04}	9.5×10^{-05}	7.3×10^{-05}
Native American Adult	4.2×10^{-04}	5.8×10^{-04}	1.1×10^{-03}	3.9×10^{-04}	1.8×10^{-04}	4.1×10^{-04}	2.9×10^{-04}	2.2×10^{-04}
Native American Child	4.4×10^{-04}	6.0×10^{-04}	1.1×10^{-03}	4.0×10^{-04}	2.3×10^{-04}	4.2×10^{-04}	3.1×10^{-04}	2.3×10^{-04}

6.0 Estimated Dose to the Onsite Intruder

The Proposed Action and each alternative have been analyzed for the onsite dose to the Rural Resident, Native American, Construction Well Driller, and Construction Home Builder. The intruder analysis differs from the offsite analysis in that the results are presented only for dose and not for risk. Risk reported is on a per-year basis. The following statements and assumptions apply to the intruder analysis:

- The rural resident and Native American intruder results are presented as an annual dose for each year the intruder is onsite
- The construction scenarios represent a one-time exposure
- Groundwater-related pathways were not considered for the construction scenarios
- Applicable assumptions and statements for the offsite analysis apply to the onsite intruder (see the introduction to Section 5.0 as well as the methodology assumptions provided in Section 4.0 for more information)
- Further details of the assumptions for the intruder scenarios are located in Section 4 of this report

6.1 Proposed Action: Onsite Intruder Results

Table 35 Onsite Intruder Results for the Proposed Action Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	3.4	25	280	310
Rural Resident Child	7.6	23	280	310
Native American Adult	7.7	32	240	280
Native American Child	14	28	240	280
Construction Well Driller	0	1.8	0.1	1.9
Construction Home Builder	0	21	1.3	22

- Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.2 Filled Site Alternative: Onsite Intruder Results

Table 36 Onsite Intruder Results for the Filled Site Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	3.9	27	490	520
Rural Resident Child	8.8	25	490	520
Native American Adult	8.8	33	410	460
Native American Child	16	29	410	460
Construction Well Driller	0	1.7	0.18	1.9
Construction Home Builder	0	20	2.3	22

- Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.3 Site Soils Cover: Onsite Intruder Results

Table 37 Onsite Intruder Results for the Site Soils Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	4.8	25	920	950
Rural Resident Child	9.3	22	920	950
Native American Adult	16	32	780	830
Native American Child	17	27	780	820
Construction Well Driller	0	1.9	0.36	2.3
Construction Home Builder	0	21	4.5	26

- Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.4 Thick Homogeneous Cover: Onsite Intruder Results

Table 38 Onsite Intruder Results for the Thick Homogeneous Cover Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	1.6	25	420	440
Rural Resident Child	4.3	23	420	440

Native American Adult	4.1	32	350	390
Native American Child	7.6	28	350	390
Construction Well Driller	0	1.8	0.17	2.0
Construction Home Builder	0	21	2.1	23

* Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events. NOTE: Some values have been rounded.

6.5 Enhanced Asphalt Cover: Onsite Intruder Results

Table 39 Onsite Intruder Results for the Enhanced Asphalt Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	1.6	25	66	93
Rural Resident Child	4.3	23	66	93
Native American Adult	4.1	32	56	91
Native American Child	7.6	28	56	91
Construction Well Driller	0	1.8	0.025	1.8
Construction Home Builder	0	21	0.32	21

- Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.6 Enhanced Synthetic: Onsite Intruder Results

Table 40 Onsite Intruder Results for the Enhanced Synthetic Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	1.6	25	440	470
Rural Resident Child	4.3	23	440	470
Native American Adult	4.1	32	370	410
Native American Child	7.6	28	370	410
Construction Well Driller	0	1.8	0.24	2
Construction Home Builder	0	21	3	24

- Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.7 Enhanced Bentonite 2056: Onsite Intruder Results

Table 41 Onsite Intruder Results for the Enhanced Bentonite 2056 Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater-Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	1.6	25	260	280
Rural Resident Child	4.3	23	260	280
Native American Adult	4.1	32	220	250
Native American Child	7.6	28	220	250
Construction Well Driller	0	1.8	0.1	1.9
Construction Home Builder	0	21	1.3	22

* Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.8 Enhanced Bentonite - Year 2000: Onsite Intruder Results

Table 42 Intruder Results for the Enhanced Bentonite - Year 2000 Alternative (mrem)*

Intruder Scenario	Exposure Pathways			Total
	Groundwater Related	External, Inhalation, Ingestion	Radon, other gases	
Rural Resident Adult	1.5	25	180	210
Rural Resident Child	4.0	22	180	210
Native American Adult	3.9	32	160	190
Native American Child	7.2	27	160	190
Construction Well Driller	0	1.9	0.069	2
Construction Home Builder	0	21	0.86	22

* Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.

6.9 Summary of Onsite Intruder Results

Table 43 summarizes the dose to the rural resident, Native American, construction well driller, and construction homebuilder. For the rural resident and the Native American, the primary difference between the offsite and onsite results is the significant contribution of indoor radon to the intruder. The results for the offsite and onsite doses follow a similar pattern because the covers that provide a good barrier to infiltration also provide a barrier to radon emanation.

The Site Soils Cover provides the least protection to the onsite intruder, primarily resulting from radon. Although both the Filled Site Alternative and the Proposed Action have the same cover design, the Filled Site Alternative shows a measurably higher dose. This shows that for onsite intruders, additional source term from filling the LLRW disposal site would have an impact on dose due to radon emanation.

The Thick Homogeneous Cover is also susceptible to emanation from radon. Although the offsite analysis showed no significant difference between this cover and the Enhanced Designs, the lack of a buried infiltration barrier results in higher radon emanation. Therefore, a buried infiltration barrier is important for reducing dose to the onsite intruder.

The best performing covers for onsite were those with a buried infiltration barrier. This Included the Proposed Action and the Enhanced Asphalt, Synthetic, and Bentontite Covers. Of these covers, Enhanced Asphalt outperformed the others because asphalt has a much lower gaseous permeability than bentonite, and it was not expected to fail like the synthetic layer in the Enhanced Synthetic Cover.[66] If future studies were to show this assumption to be false, then the Enhanced Asphalt would not be significantly better for onsite dose than the other covers with buried infiltration barriers.

The differences in the alternative cover designs have very little impact on the construction workers, as both the well driller and the homebuilder spend a small amount of time onsite. For the well driller, the dose is less than 3 mrem and is considered minimal. The homebuilder gets a larger dose because of the increased time assumed spent near the contaminated waste removed by the well driller. The dose for the homebuilder ranges from 21-23 mrem. Considering the small amount of time the homebuilder remains onsite, this dose could be considered significant.

Due to the contribution of radon, potential increases or decreases in the dose estimates will occur, depending upon the volume of NARM disposed. See Section 9 for a discussion on the impact of the NARM volume disposed.

Table 44 summarizes the risk for the various intruder scenarios. Differences between the Native American and rural resident scenarios are greater due to the 70-year basis for lifetime estimates, as compared to the 30-year lifetime used for the rural resident.

[66] The results indicate that a greater dose would be received as a result of the Enhanced Synthetic Alternative, as compared to the Thick Homogeneous Alternative. This is due to an assumption regarding the long-term effectiveness of the synthetic barrier for the Enhanced Synthetic Cover. The assumed degradation of the barrier, combined with the gravel drainage layer included below the barrier, would result in a lesser total effective thickness for the Enhanced Synthetic Cover, as compared with the Thick Homogeneous Cover.

Table 43 Summary of Dose to Onsite Individuals (mrem)*

Scenario	Alternatives							
	Proposed Action	Filled Site	Site Soil Cover	Thick Homogeneous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite – Year 2056	Enhanced Bentonite – Year 2000
Rural Resident Adult	310	520	950	440	93	470	280	210
Rural Resident Child**	310	520	950	440	93	470	280	210
Native American Adult	280	460	830	390	91	410	250	190
Native American Child**	280	460	820	390	91	410	250	190
Construction Well Driller	1.9	1.9	2.3	2	1.8	2	1.9	2
Construction Home Builder	22	22	26	23	21	24	22	22

*Doses for Rural Residents and Native Americans are per year. Doses for construction workers are one-time events.
**Insufficient information exists to segregate the dose to the child.

Table 44 Summary of Risk to Onsite Individuals (risk of fatal cancer per person)*

Scenario	Alternatives							
	Proposed Action	Filled Site	Site Soil Cover	Thick Homogeneous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite – Year 2056	Enhanced Bentonite – Year 2000
Rural Resident Adult	4.6×10^{-03}	7.8×10^{-03}	1.4×10^{-02}	6.7×10^{-03}	1.4×10^{-03}	7.0×10^{-03}	4.3×10^{-03}	3.2×10^{-03}
Rural Resident Child**	4.6×10^{-03}	7.8×10^{-03}	1.4×10^{-02}	6.7×10^{-03}	1.4×10^{-03}	7.0×10^{-03}	4.3×10^{-03}	3.2×10^{-03}
Native American Adult	9.7×10^{-03}	1.6×10^{-02}	2.9×10^{-02}	1.4×10^{-02}	3.2×10^{-03}	1.4×10^{-02}	8.8×10^{-03}	6.7×10^{-03}
Native American Child**	9.7×10^{-03}	1.6×10^{-02}	2.9×10^{-02}	1.4×10^{-02}	3.2×10^{-03}	1.4×10^{-02}	8.9×10^{-03}	6.7×10^{-03}
Construction Well Driller	9.5×10^{-07}	9.5×10^{-07}	1.2×10^{-06}	1.0×10^{-06}	9.0×10^{-07}	1.0×10^{-06}	9.5×10^{-07}	1.0×10^{-06}
Construction Home Builder	1.1×10^{-05}	1.1×10^{-05}	1.3×10^{-05}	1.2×10^{-05}	1.1×10^{-05}	1.2×10^{-05}	1.1×10^{-05}	1.1×10^{-05}

*Doses for Rural Residents and Native Americans are lifetime doses. Doses for construction workers are one-time event
**Insufficient information exists to segregate the dose to the child.

7.0 MODEL TOXICS CONTROL ACT SCENARIOS AND ANALYSIS

The Washington State Department of Ecology requested that two scenarios be evaluated as part of this EIS [Staats, 1999]. They are a modified MTCA Method B residential scenario and a modified MTCA Method C industrial scenario.

7.1 Scenarios

The modified MTCA Method B residential scenario is a combination of the risk equations specified in Washington Administrative Code (WAC) 173-340-720 through 173-340-750, and the corresponding exposure pathways for residential use found in the Department of Health's (DOH) Hanford Guidance for Radiological Cleanup, WDOH/320-015. The modified MTCA Method C industrial scenario is a combination of the risk equations specified in WAC 173-340-720 through 173-340-750, and the corresponding exposure pathways for industrial/commercial found in the Guidance. WAC 173-340-730 is not applicable to either scenario, as it is not expected that the site or any remedial activity under consideration will impact surface water. Ecology also asks that the modified Method C scenario specifically include groundwater ingestion at the rate of 500 L/year, and that the soil contaminant transfer to groundwater, as specified in WAC 173-340-740 (4)(b), be evaluated. The addition of groundwater intake to the modified Method C scenario represents a change to the Hanford Guidance exposure pathways that currently does not include this parameter. The soil contaminant transfer to groundwater evaluation is included to ensure consistency with similar scenarios evaluated elsewhere.

Table 45 provides a comparison of the input values from MTCA, WAC 173-340-720, 745, 750, and values from the Department of Health's Hanford Guidance document. It is assumed MTCA Method C values for non-radiological constituents would be applicable to the disposal site.

Table 45 Exposure Parameters Comparison

Exposure Factors	MTCA – Method C Formula Values	DOH Hanford Guidance – RESRAD Industrial	Other MTCA Method C	
			Exposure Factors	Formula Values
Inhalation rate	5000 m^3/year absorption percentage –1.0	7300 m^3/year		
Mass loading for inhalation rate	NS	.0001g/cm^3		
Dilution length for airborne dust	NS	3 meters		
Exposure duration	30 years – air 20 years – soil 30 years -- gw	25 years		
Shielding factors	NS			
Inhalation		0.4	Soil cleanup values	

Exposure Factors	MTCA – Method C Formula Values	DOH Hanford Guidance – RESRAD Industrial	Other MTCA Method C	
			Exposure Factors	Formula Values
External y		0.8	Risk level	1 x 10^{-5}
Time fractions	Frequency of contact - .4		Average body weight	70 kg
Indoors (all work time outdoors)	NS	0.22	Compliance depth	0 – 15'
Outdoors (1000 hrs, 50% of work time in contamination)	NS	0.014	Hazard quotient	<1
Shape factor for external *y*	NS	1	Lifetime	70 yrs
Soil ingestion	50 g/yr	36.5 g/yr		
Drinking water intake	500 l/yr	NA		
Fraction of contaminated drinking water	1			
Depth of soil mixing layer	Thickness of contamination - 4.6m	Thickness of contamination - 4.6 m		
Groundwater/ surface water fractional usage		NA		
drinking water	1	NA		
Household usage				

(NS = not specified; NA = not applied)

A table comparing MTCA Method B residential parameters with applicable guidance is included in Table 3. Where specific information for the residential scenario is missing, the WDOH Guidance document and the parameters in this EIS are used to supplement the MTCA Method B parameters.

7.2 Estimated Onsite and Offsite Dose to the MTCA Method C Industrial Individual

Table 46 provides the results of the MTCA industrial analysis for both onsite and offsite individuals. For the onsite intruder, the overwhelming contributor to dose is the indoor exposure to radon. The majority of dose for the offsite individual is from the ingestion of contaminated groundwater.

Table 46 Summary of Dose to Method C Individual (mrem/y)

	Proposed Action	Filled Site	Site Soils Cover	Thick Homogen-eous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite - Year 2056	Enhanced Bentonite - Year 2000
MTCA Method C Intruder	40	64	120	56	14	59	37	30
MTCA Method C Offsite	2.1	3.2	5.7	2.7	0.9	2.8	1.9	1.2

Of greater value may be the estimated doses for the industrial scenario converted to risk (of fatal cancer). Table 47 presents those results for both the onsite and offsite individual.

Table 47 Summary of Risk to Method C Individual

MTCA Risk Estimates	Proposed Action	Filled Site	Site Soils Cover	Thick Homogen-eous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite – Year 2056	Enhanced Bentonite - Year 2000
MTCA Method C Intruder	6.0×10^{-04}	9.5×10^{-04}	1.8×10^{-03}	8.4×10^{-04}	2.1×10^{-04}	8.9×10^{-04}	5.5×10^{-04}	4.4×10^{-04}
MTCA Method C Offsite	3.2×10^{-05}	4.8×10^{-05}	8.6×10^{-05}	4.0×10^{-05}	1.4×10^{-05}	4.2×10^{-05}	2.8×10^{-05}	1.8×10^{-05}

7.3 Estimated Onsite and Offsite Dose to the MTCA Method B Residential Individual

Table 48 provides the results of the MTCA residential analysis for both onsite and offsite individuals. For the onsite intruder, the overwhelming contributor to dose is the indoor exposure to radon. The majority of dose for the offsite individual is from the ingestion of contaminated groundwater.

Table 48 Summary of Dose to Method B Individual (mrem/y)

	Proposed Action	Filled Site	Site Soils Cover	Thick Homogen-eous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite - Year 2056	Enhanced Bentonite - Year 2000
MTCA Method B Intruder	300	500	920	430	90	460	280	200
MTCA Method B Offsite	6.00	9.00	15	6.8	2.0	6.8	4.4	3.3

Table 49 converts the residential results from dose to risk of fatal cancer.

Table 49 Summary of Risk for Method B Individuals

	Proposed Action	Filled Site	Site Soils Cover	Thick Homogen-eous Cover	Enhanced Asphalt	Enhanced Synthetic	Enhanced Bentonite – Year 2056	Enhanced Bentonite - Year 2000
MTCA Method B Intruder	4.5×10^{-03}	7.5×10^{-03}	1.2×10^{-02}	6.5×10^{-03}	1.3×10^{-03}	6.8×10^{-03}	4.1×10^{-03}	3.1×10^{-03}
MTCA Method B Offsite	9.0×10^{-05}	1.4×10^{-04}	2.3×10^{-04}	1.0×10^{-04}	3.0×10^{-05}	1.0×10^{-04}	6.5×10^{-05}	5.0×10^{-05}

7.4 Summary of Results for the MTCA Industrial and Residential Scenarios as Applied to the LLRW disposal site

The tables above provide an estimate of the results if MTCA were to be applied to the disposal site. Although numerous assumptions regarding exposure parameters are made where specific guidance from MTCA is not available, the parameters used are derived from published analysis using MTCA at the Hanford Site, or from the use of the Hanford Guidance document developed by WDOH. The results from the MTCA residential analysis are quite similar to the results reported for the rural resident adult in Tables 33 and 43. The onsite intruder results would apply if the point-of-compliance were chosen as an onsite location. If an alternative point-of-compliance were chosen, such as the fenceline boundary, then the results calculated for the offsite individual would apply.

8.0 ECOLOGICAL RISK

A simple ecological model of the LLRW disposal site is a food web including grass, the great basin pocket mouse, the mule deer, the coyote, and the hawk. This represents the contaminated vegetation, first-order herbivores, and carnivores. Other ecological studies have been conducted which also include the riparian system by the Columbia River (Tank Waste Remediation System Environmental Impact Statement [U.S. DOE, 1996], and the Columbia River Comprehensive Impact Assessment, CRCIA [U.S. DOE, 1998]). The LLRW disposal site is nearly 17 kilometers from the Columbia River. It is more likely that the terrestrial ecosystem would be impacted before the Columbia River, and thus the desert system will be studied. It may be emphasized that even this scenario is highly unlikely, and requires that an intruder bring contamination to the surface. The following scenarios and equations were taken and adapted from the TWRS EIS.

8.1 Source

The contamination in the LLRW disposal site is to be buried below the zone in which translocation is likely to occur from biotic processes. The LLRW disposal site is designed to preclude intrusion from roots or burrowing creatures. For the purpose of this analysis, it is assumed that a human intruder has ignored or missed any warning markers, and has disturbed the LLRW disposal site by drilling a well through the waste zone. The dimensions of the drill hole are 30 centimeters in diameter, and 11.3 meters deep through the waste zone, resulting in 0.8 cubic meters of waste removed from the LLRW disposal site. It was further assumed that the radionuclide concentration did not vary within the LLRW disposal site. The debris removed from the hole was scattered over an area 1500 square meters, and was further assumed to be mixed uniformly to a depth of 15 centimeters by the time the scenario takes place.

8.2 Vegetation

The vegetation growing on the plot of contaminated land is assumed to be nutritionally substantial enough to produce seeds to support the pocket mouse, as well as vegetation to support the mule deer. The vegetation will be modeled as grain and leafy vegetation, and referred to as “grass.” The effective radius of the vegetation was assumed to be 1.4 centimeters [U.S. DOE, 1996]. Relevant parameters can be found in Table 50.

8.3 Herbivores

The great basin pocket mouse has a small range, relative to the area of contamination; therefore 100% of the mouse’s forage is taken from the contaminated area. The mule deer’s home range exceeds the contaminated area, so 0.012% of its forage was assumed to be grown in the contaminated zone. Both the mouse and deer are exposed via ingestion of food and soil, and the mouse is exposed externally from contamination on the ground. Specific parameters for each animal are listed in Table 50.

8.4 Carnivores

For the purposes of this assessment, the coyote and the hawk were assumed to consume only pocket mice. They have home ranges greater than the contaminated area, so the fraction of food assumed to be contaminated was set equal to the contaminated area, divided by the respective home ranges. Relevant parameters are shown in Table 50.

8.5 Applicable Standard

The estimated dose rates to organisms were compared against dose rate standards. The standard most easily conceptualized and defined is the 0.1 rad/day dose, below which the intake is expected to have no adverse effect to terrestrial organisms [IAEA, 1992].

8.6 Exposure

The concentration in the soil is estimated as:

Equation 40

$$CS_i = CW_i * H * \Pi * (d/2)^2 / (2500*.15),$$

Where

- CS_i = Concentration of radionuclide i in the soil (Ci/m^3_{soil})
- CW_I = Concentration of radionuclide i in the waste form (Ci/m^3_{waste})
- H = Thickness of waste in LLRW disposal site (m)
- Π = 3.1416…
- d/2 = radius of drill hole (m)
- 2500 = area of contamination (m^2)[67]
- .15 = average depth of contamination (m).

The concentration in the grain and vegetation is calculated by estimating the root uptake and deposition on the plant.

Equation 41

$$CG_{v,i} = CS * TF_v * WD_v + \text{plant deposition}_v * 1500 \text{ kg/m}^3$$

Where

- $CG_{v,i}$ = Concentration of radionuclide i of food type, v, for vegetative or grain part (Ci/kg wet plant)
- TF_v = Transfer factor soil to dry plant part, v (Ci/kg dry plant per Ci/kg dry soil).

[67] A discontinuity exists in the area of contamination assumed. The ecological risk assessment used 2500 m², whereas the radiological risk assessment for humans assumed that 1500 m² is used. The increased area in the ecological risk assessment has no meaningful impact on the dose calculated.

- WD_v = Wet to dry ratio for vegetation type v;
- Plant deposition = deposition on plant type v * concentration in air (Ci/kg)

The concentrations in the pocket mouse and mule deer are calculated by summing the contributions from the ingestion of grain and soil. Inhalation is not expected to play a significant role in the contribution to concentration. The equilibrium concentration for the herbivores is given by the intake rate, divided by the effective biological decay constant. The equilibrium concentration from ingestion is given in the following equation:

<u>Equation 42</u>

$$CM_{ai} = ((CG_{vi} * IR_{v,a} + CS * IS_a) * f_1 * HR / (M_a * T_{eai}))$$

Where

- $CM_{a,i}$ = concentration of radionuclide i in animal, a (Ci/kg)
- IR_{va} = intake rate of food v by animal a, (kg wet/day)
- IS_a = intake rate of soil by animal a (kg/d)
- f_1 = fraction of intake retained in animal (-)
- HR = fraction of animal's home range derived from contaminated zone
- M_a = mass of animal
- T_{eai} = effective biological loss constant for radionuclide i in animal type a (d^{-1})

The calculation of the body burdens for the carnivores is calculated based on the body burden of the pocket mouse prey. It is assumed that the exposure duration is long and that equilibrium concentrations are reached:

<u>Equation 43</u>

$$CM_{2a,i} = (IR_{pa} * CM_{ai} * f_1)/(M_{2a} * T_{e2ai})$$

Where

- $CM_{2a,i}$ = the body burden in the carnivore a of radionuclide i (Ci/kg)
- IR_{pa} = the intake rate of the prey by carnivore a (kg/d)
- f_1 = the fraction of intake retained in body mass (-)
- M_{2a} = the body mass of carnivore 2a (kg)
- T_{e2ai} = the effective biological loss constant of radionuclide i in the carnivore a (1/d)

Calculation of internal dose (rad/day) is calculated in the following equation:

Equation 44

$$R_{a,I} = CM_{ai} * E_{ai}$$

- $R_{a,I}$ = Dose rate to animal a from radionuclide i,
- E_{ai} = Effective absorbed energy rate for nuclide i per unit activity in organism a (kg rad per Ci d)
- E_{ai} = ,$_{ai}$ MeV/dis x 3.7×10^{10}dis/s*Ci x 86400s/d x 1.602×10^{-11}kg rad/MeV = 5.12×10^{4} ,$_{ai}$ where ,$_{ai}$ is the effective absorbed energy for nuclide i in organism a (Mev/dis).

The external dose to the pocket mouse is:

Equation 45

$$R_{ext,i} = CS_i * T * DF_{gnd,\, i} * F_{ruf}$$

Where

- $R_{ext,\, i}$ = external dose rate from ground for radionuclide i
- T = time of exposure to ground for animal a
- $DF_{gnd,\, i}$ = dose factor for external exposure to ground for radionuclide i (rad/d per Ci/kg)
- F_{ruf} = surface roughness factor (-)

8.7 Results

The estimated doses to organisms are shown in Table 51. No doses exceed the 0.1-rad/d level set forth by IAEA as a level above which observable effects are expected. In fact, only the external dose to the pocket mouse approaches the 0.1-rad/d level, and the dose is at most 0.030 rad/d. The doses to all other organisms would be below this level by a factor of 11 or more. All other organisms have much smaller estimated dose rates, due to their large home ranges relative to the area of contamination.

The ecological model is different from that of the human receptors; however, the doses are reasonable when compared to those received by the humans. The factors from the soil and plant scenarios are the same, so the mouse and the cow are ingesting the same concentrations in the plant. Other factors such as animal size and metabolism will cause differences in the calculated values, but the concentrations in the top-order carnivores are relatively comparable, within a few orders of magnitude difference. Overall, the two models complement each other well.

Table 50 Parameters for Ecological Scenario

Parameters	Plant	Great Basin Pocket Mouse	Mule Deer	Coyote	Red-tailed Hawk
Size (kg)	N/A	0.024	57	9.8	1.4
Food ingestion rate (kg/d)	N/A	0.0327	3.7	1.3	0.165
Soil ingestion rate (kg/d)	N/A	.000262	0.02	N/A	N/A
Home range (ha)	N/A	0.0907	0.24	302	218
Effective radius (cm)	1.4	2	30	30	5

Table 51 Estimated Doses to Organisms

	rad/d
Dose to plant	.000023
Mouse dose rate from food ingestion	.0060
Mouse dose rate from soil ingestion	.012
External dose to mouse	.030
Mule Deer Dose rate from ingested contamination	.00000076
Coyote total dose from ingestion	.0014
Hawk dose rate from ingestion	.0032

9.0 NARM

The preceding analyses for offsite and onsite intruder doses (Sections 5 and 6) considered all radioactive waste disposed at the site, including both low-level and NARM. This analysis artificially segregates NARM waste from the total waste at the site to determine the incremental impacts of disposing of NARM. Several hypothetical NARM volumes are evaluated. For the preceding analyses, it was assumed 36,700 ft^3/year of NARM is placed in the LLRW disposal site. The NARM analysis in this section evaluates the incremental dose of disposing NARM at including 8,600 ft^3/year, 36,700 ft^3/year, 50,000 ft^3/year, and 100,000 ft^3/year, and includes both diffuse and discrete sources of NARM.

The NARM analysis is a simplified version of the previous analyses performed in Sections 5 and 6. This NARM analysis looks exclusively at the impact to the rural resident adult, starting at the end of the 107-year institutional control period. Of the seven isotopes contained in NARM, only radium 226 and lead 210 have long enough half-lives and enough source term to impact dose following institutional controls.[68] The source term for NARM [Blacklaw, 1998] contains no radionuclides that are of concern for the groundwater pathway. As a result, exposure from NARM must occur through either direct exposure or diffusion through the waste.[69]

9.1 NARM Results

The predicted onsite and offsite intruder dose for the rural resident adult is presented in Tables 52 and 53.

[68] The source term input file for NARM [Blacklaw, 1998] contained a radionuclide consisting of a summation of lesser radionuclides listed as "others." This grouping was not considered in the calculations.

[69] Two radionuclides have the capability to diffuse through the waste as a gas: H-3 and the daughter of radium 226 (radon 222). H-3 has the combination of an extremely small source term ($8x10^{-3}$ pCi/g for a 100,000-cubic feet-per-year disposal volume in the year 2163), and a short half-life. This effectively removes tritium as a nuclide of concern for diffusion. Performing the calculations for the ambient air concentration as in Section 3.4.3 can assess the estimated impact as a result of gaseous diffusion. Starting with an activity of 684 curies in the year 2056, the resulting concentration is 1.65 curies in 2163. Estimating the tritium surface flux as $3x10^{-5}$ pCi/m^2*s results in an ambient air concentration of $2x10^{-6}$ pCi/l. Using the NCRP conversion factor of $9.5x10^{-5}$ mrem/pCi/l results in a dose of $4x10^{-13}$ mrem/yr. The tritium results are not further considered in the NARM analysis.

Table 52 Onsite Incremental NARM Dose For the Rural Resident Adult (mrem/year)

Alternatives	NARM Disposal Volumes (ft^3/yr)			
	8,600	36,700	50,000	100,000
Proposed Action	15	65	88	180
Filled Site	54	230	310	620
Site Soils	7	30	40	81
Thick homogeneous cover	22	96	130	260
Enhanced Asphalt	4	15	21	42
Enhanced Synthetic	24	100	140	280
Enhanced Bentonite 2056	14	59	81	160
Enhanced Bentonite -Yr 2000	2	30	40	81

Table 53 Offsite Incremental NARM Dose For the Rural Resident Adult (mrem/year)

Alternatives	NARM Disposal Volumes (ft^3/yr)			
	8,600	36,700	50,000	100,000
Proposed Action	0.4	1.5	2.1	4.2
Filled Site	1.3	5.5	7.4	15.1
Site Soils	0.1	0.4	0.6	1.2
Thick homogeneous cover	0.5	2.3	3.1	6.2
Enhanced Asphalt	0.1	0.4	0.5	1.0
Enhanced Synthetic	0.6	2.4	3.3	6.6
Enhanced Bentonite 2056	0.3	1.4	1.9	3.8
Enhanced Design - Yr2000	0.0	0.1	0.1	0.3

For all alternatives, the incremental impact from NARM is relatively low. The dose is highest with the Filled Site Alternative, showing that increased NARM volumes associated with filling the LLRW disposal site to capacity do have an impact on dose at the site. Reviewing the results of Table 52 indicates that the alternatives that close the site in the year 2000 have relatively small contributions from NARM, as is expected from the small volume disposed over the next several years. The remaining alternatives for the 2056 closure date are ranked in a slightly different order than the intruder analysis in Section 6, due to the lack of any contributors to groundwater contamination. The Enhanced Asphalt Alternative with the asphalt barrier provides the lowest estimated dose, followed by the clay barrier for the Enhanced Bentonite Alternative. The Proposed Action Alternative (also with a clay barrier) provides a lower estimated dose than the Thick Homogeneous Alternative, due to the clay barrier used in the Proposed Action and the assumed long-term failure for the synthetic barrier in the Enhanced Synthetic Alternative.

Incremental impacts to the onsite intruder are significant from NARM. The results are linear – the more NARM disposed, the higher the dose. This is consistent with the analysis for the total waste disposed that showed that radon emanation is the primary contributor to the onsite dose.

For all four volumes considered for analysis, radon contributes over 90% of the total dose. Soil ingestion and external radiation provide the remainder of the dose. It should be noted that the offsite impacts from radon 222 are not affected by the institutional control period. A rural resident living at the LLRW disposal site boundary prior to the end of the institutional control period could receive a similar dose as that shown in Table 53.

10.0 Radiological Risk Uncertainty Analysis

Chapters 5 and 6 present the single-point estimates of dose and risk for closure of the commercial LLRW disposal site. While reported dose or risk values may be high for the single-point estimates, the uncertainty for these estimates is several orders of magnitude, as will be shown in this analysis. Estimates of dose or risk from exposure to radiation are generally recognized to have high uncertainty. This uncertainty, combined with uncertainties associated with the prediction of contaminate movement in the groundwater and habits and lifestyles of individuals thousands of years in the future, make the overall uncertainty even higher. For the single-point estimates of dose and risk, conservative input values were intentionally used. The results of this uncertainty analysis also indicates that the predicted single-point dose and risk estimates exceed the predicted 95 percentile value in almost all cases, further confirming the conservative nature of the estimates.

The purpose of this uncertainty analysis is to provide individuals with a more realistic estimate of the potential exposures in the future, and to take into consideration the likelihood of a rural resident (subsistence) scenario. This realism is included in the uncertainty analysis by taking into consideration the possible range of a given parameter such as the drinking water intake rate, amount of food grown, time spent on the contaminated land, etc. Information available for parameters is reviewed, and a distribution of potential results is derived and included. Once all of these parameters are taken into consideration, the overall dose and risk model is run, using a Monte Carlo approach. This approach allows each parameter specified to vary within a predicted distribution in order to determine the most likely dose to an individual, as well as the upper bound of doses. The list of parameters chosen for the uncertainty analysis is included in Attachment 1, the Uncertainty Parameters Table.

The uncertainty analysis has been divided into five steps:
1. Source Term Uncertainty
2. Groundwater Uncertainty
3. Uncertainties Associated with Exposure Parameters
4. Radiation Dosimetry Uncertainty
5. Uncertainties Associated with Risk Projection Models

The source term uncertainty is only qualitatively discussed, as the potential error for Tc-99 and I-129 would overwhelm the effects for all other analysis. Groundwater uncertainty, in addition to the brief discussion below, is included with the Groundwater Pathway Analysis in Appendix 3. Uncertainties associated with exposure parameters are considered in three general divisions. The first division is physiological parameters such as body weight and inhalation rate. The second division is behavioral factors such as the drinking water rate, time spent indoors, etc. The third division is environmental factors such as plant uptake rates, radon diffusion rates, etc. Radiation dosimetry uncertainty includes a wide application of probable uncertainty. The uncertainty is limited to individual differences related to organ size, uptake, and retention. Other uncertainties are qualitatively addressed. Finally, the estimated uncertainty associated with risk is discussed and quantified.

10.01 The Focus of the Uncertainty Analysis

The results presented in the EIS are based upon a single-point estimate for a number of scenarios. The input parameters used in the scenarios are intended to serve the following purpose:

- For the rural resident scenario, the dose and risk estimates are designed to be sufficiently protective of the general population through the use of a rural (subsistence) setting. The dose results are intended to estimate the 95 percentile.
- For the Native American scenario, the dose and risk estimates are intended to represent the average member of this critical group.
- For the child scenarios, the results are intended to represent the endpoints used in the corresponding adult scenarios.
- For the construction scenarios, the results are intended to represent the 95 percentile.

For these scenarios, however, one cannot adequately determine whether the target dose goals are met without the use of an uncertainty analysis for the input parameters. Limited data exist to assess the uncertainty of the Native American scenario. An uncertainty analysis for the Native American scenario is therefore not performed. The estimated dose to the well driller and the home builder are significantly less that the other scenarios and the onsite dose limit; therefore, no uncertainty analysis for these scenarios are considered. Sufficient information is available for the rural resident scenario (general population) to arrive at an overall uncertainty estimate.

The uncertainty analysis for the Rural Resident Adult includes a number of parameters that allow for an estimate of the likelihood of an individual of the general population to live in a rural subsistence setting. The two key parameters that allow for the inclusion of likelihood of this information are the locally grown food consumption rates and the hours spent indoors and outdoors. These data are available in the most recent version of the EPA Exposure Factors Handbook [U.S. EPA, 1997].

The Monte Carlo analysis [Decisioneering, 1996] is used to determine the uncertainty surrounding the single-point estimates for the rural resident scenario. The inputs for the Monte Carlo analysis are the probability distributions for key parameters. The distributions used in this analysis are considered subjective, as they are based on the most current information that will be subject to change as more information becomes available in the future.

The sensitivity analysis for this model is performed by Crystal Ball [Decisioneering, 1996] and estimates the sensitivity by calculating rank correlation coefficients between all of the input parameters and the end result (the dose or risk). The modeler must first make a few assumptions about what parameters are likely to be an important contribution to the final results prior to conducting the first sensitivity analysis run. This information is obtained from other environmental studies performed in recent years [U.S. DOE, 1996; U.S. DOE, 1998; and NCRP, 1999].

The shape of the probability distributions reflect the depth of information available for a given parameter [NCRP, 1996]. For parameters such as the weathering constant, sufficient data exist to estimate the range and likely value, but insufficient information exists to further define the distribution. The weathering constant is therefore assigned a triangular probability distribution. Greater information exists on the drinking water (tap water) intake rate for the general population and allows for further definition of the distribution as log-normally distributed, with estimated percentiles on the distribution. In some instances, parameters are assigned a triangular distribution due to their minor impact on the overall dose estimate. The triangular distribution for the irrigation rate is a good example of an area where increased research or modifying data on the overall range and distribution would not affect the overall results.

10.02 Segregation of Uncertainty and Variability

In uncertainty analyses, two types or sources of variation exist: uncertainty and variability [Decisioneering, 1998]. Parameters exhibit uncertainty, generally due to insufficient information about the true value (or range of values). The wet-to-dry conversion factor for plants is an example of a parameter with some uncertainty. Each plant of interest has different moisture content. If one is able to quantify the moisture content of all of the plants consumed, with their appropriate consumption weight, then an accurate means and range can be used.[70] Parameters exhibit variability due to the random fluctuations within a population. Examples include intake estimates of food or water (i.e., no two individuals are exactly the same).

It is also possible for parameters to exhibit both uncertainty and variability. Such parameters are termed second-order random variables. The soil-to-plant concentration factor is an example of a parameter with uncertainty and variability about the true value. The soil-to-plant concentration factor would exhibit some variation when only one plant is of interest. This variation is due to differences in the chemical form of the radionuclide, soil characteristics, distribution of the radionuclide within the soil, and internal contaminate distribution within the plant [Till and Meyer, 1983]. In addition to the individual plant variability, uncertainty also exists due to the many varieties of plants that are grown and consumed. Due to time and research limitations, parameters will be identified as sources of either uncertainty or variability (and not segregated), depending upon the relative contribution of the sources of variation.

10.1 Source Term Uncertainty

A majority of the I-129 and Tc-99 disposed at the commercial LLRW disposal site is commercial reactor waste. The quantity of Tc-99 and I-129 reported on disposal manifests is based upon scaling factors. In actual practice, the minimum detectable

[70] The individual variability among a given type of vegetable or fruit is assumed to be small, and is therefore neglected.

activity (MDA) of I-129 and Tc-99 was used for the calculation of the scaling factor, and resulted in overestimates of the actual quantities of Tc-99 and I-129 by anywhere from 100 to 10,000 [U.S. NRC, 1994]. The overestimate resulted from the use of an upper bound (the MDA), as opposed to determining the actual concentration in the waste or by utilizing a more accurate scaling factor. A more accurate method for determining the disposal quantities of Tc-99 and I-129 has been developed by Vance and Associates [U.S. NRC, 1994; Vance, 1998]. The improved methodology, if applied, would reduce the over-conservatism to within a factor of 10 (as opposed to the current range of 100 to 10,000). It is very likely that if the source terms for Tc-99 and I-129 were accurately modeled, very little I-129 or Tc-99 would be predicted. For this uncertainty analysis, the potential uncertainty in the Tc-99 and I-129 source term is not considered, in order to prevent overwhelming other uncertainties.

As discussed in Section 3.1.1, uranium was under-reported in the 1960's and early 1970's. An inventory audit is currently underway for the uranium source term. Initial indications for U-238 are that the source term is about 20% under-reported. A large correction is expected for the U-235 source term that will significantly reduce the reported values.[71]

10.2 Groundwater Uncertainty

The uncertainty analysis for the groundwater modeling provided the output in terms of predicted groundwater concentrations. The groundwater uncertainty output is 1,000 realizations for each radionuclide for the 15 selected time periods of interest (200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1500, 2000, 2500, 5000, and 10000 years). The resulting radiological uncertainty analysis incorporated these groundwater realizations by randomly selecting among the realizations, while maintaining the correlation among all the radionuclides for a given timeframe of interest. See Appendix 3, Groundwater Pathway Analysis, for the uncertainty analysis discussion related to the groundwater portion.

10.3 Uncertainties Associated with Human Exposure Assessment

This section includes a review of some of the parameters influencing the dose or risk. The distributions and references for all of the parameters are located in Attachment 1.

Consumption Rate

Information on the consumption of vegetables, fruits, dairy products, meats, and eggs is summarized in the EPA Exposure Factors Handbook [U.S. EPA, 1997]. The data provided in Chapter 13 of Volume II for western states is specifically applied, as this directly relates to the consumption of homegrown products. As the rural resident is assumed to be a member of the overall population, the consumption distributions has the fraction of the overall population consumption applied, in order to truly represent the

[71] The uranium source term used in this EIS was magnified to physically improbable quantities in order to allow for modeling in this EIS to proceed, yet be sufficiently conservative. Due to being solubility-controlled in the groundwater analysis, the uranium source term has only a minor impact on dose.

population as a whole. A limitation of these data is that the reported values are provided as g/kg-day, as the intake rates are indexed to the body weights of the individuals in the survey. The survey included adults and children. The g/kg-day ingestion values are multiplied by the assumed 70-kg adult weight in order to arrive at a consumption (g/day) rate basis used throughout the EIS calculations. The log-normally-distributed data's 5% and 95% values are provided in Table 54.

Table 54 Consumption Rates for Food Products (g/day)

Food Type	5%	95%
Fruit	4	600
Leafy Vegetables	0.25	63
Non Leafy Vegetables	1	290
Beef	1.1	131
Poultry	0.9	106
Dairy	12.6 ml/d	2000 ml/d
Eggs	14.4	95.2

Some simplifying assumptions made in the conversions:

- Milk is assumed to be the total dairy consumption. The density of milk is assumed the same as water.
- Data from the *Exposure Factors Handbook* are only available for total meat for consumers only. These data are applied to beef and poultry by using NUREG 5512. Table 13-8 of the *Exposure Factors Handbook* is used to obtain those fractions.
- The *Exposure Factors Handbook* provides combined data for total vegetables. These data are then applied to leafy and non-leafy vegetables by assuming the fractions of consumption provided in NUREG 5512 (17.8% for leafy vegetable intake, 82.2% for non-leafy vegetable intake).

Drinking Water Intake

The range and distribution provided by the EPA *Exposure Factors Handbook* are provided from fitted distributions from Roseberry and Burnmaster. The 5% value is 0.5 l/d; the 95% is 2.5 l/d. Not included in this distribution is the consideration of increased drinking water in a temperate climate. Elevated temperatures exist in the Hanford area for about three to four months of the summer and may affect the distribution, although this possibility has not been explicitly analyzed. The 3-l/d drinking water value used in the radiological analysis for this EIS is approximately 97.5% value for this distribution. For the model, the intake frequency is assumed to be 365 d/y, as the intake rate is adjusted for frequency.

Distribution Coefficient – Tc-99 and Cl-36

The distribution coefficient information is obtained from Appendix E of the *Composite Analysis* [Kincaid, et al, 1998]. For the dry disposal site, the estimated range of the distribution coefficient extends from -2.8 to 0.6, with a most likely value of 0. The negative value for the distribution coefficient cannot be completely modeled without the resulting infiltration rates estimates becoming negative as well.[72] The resulting range is truncated with a lower bound of -0.07 and an upper bound of 0.6. The distribution of the distribution coefficient is a step-wise distribution, with a mode of 0 and an exponential decay to 0.6 [Fayer, 1999].[73]

Soil-to-Plant Concentration Factors of Tc-99 for Leafy Vegetables and Grasses

Information on the 5% and 95% values for both grasses and leafy vegetables is obtained from the International Atomic Energy Agency/International Union of Radioecologists [IAEA, 1994]. The upper bound on the concentration factor is limited by the amount of contaminate available for uptake; i.e., it is possible to model a concentration factor that results in a greater amount of contamination removed from the soil than is deposited in the soil from irrigation. As a result, the upper bound value is limited to the total contamination deposited in a season.[74]

- For leafy vegetables, the geometric mean is taken as 210; the geometric standard deviation (GSD) is 1.5. The upper bound on the log-normally-distributed parameter is 430.
- For grasses, the geometric mean is taken as 210; the geometric standard deviation (GSD) is 2.3. The upper bound on the log-normally-distributed parameter is 680. The upper bound value for grasses is higher than the calculated mass limited value for leafy vegetables, due to the lower estimated plant yield for grasses, as compared to leafy vegetables (i.e., a smaller amount of potential contaminate removal).

Wet-to-Dry Conversion Factors

The EPA *Exposure Factors Handbook* provided information on the moisture content, as well as a table for consumption rates of the various food products, that allowed the weighting of the results to obtain an overall weighted mean value. A triangular distribution was used, with the range being the highest and lowest reported values.

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[72] Negative Kd values are possible, as the scale is in relation to the speed of water moving in a soil column. The negative charge of Cl-36 and Tc-99 has the effect of repelling the ions from the surface of the soil particles. This can cause the ions to remain in the larger soil pores, causing them to move down preferential pathways, and in a sense, travel faster than water [Napier, 1999b].

[73] NOTE: The distribution coefficient and any other groundwater-related parameter for this uncertainty discussion are only assumed to apply to the contaminated groundwater that is applied to the food products and used for drinking water. The distribution coefficient values mentioned here affect groundwater movement only after the groundwater has been contaminated. In short, this is a non-recycling model.

[74] For Cl-36 and Tc-99, contaminant transport is sufficiently fast to result in removal of the contaminant prior to the next growing season.

- For leafy vegetables, the weighted mean moisture content is 0.93, with a range of 0.86 to 0.95
- For non-leafy vegetables, the weighted mean moisture content is 0.90, with a range of 0.59 to 0.96
- For fruits, the weighted mean moisture content is 0.80 with a range of 0.74 to 0.92

10.3.1 Critical Parameters for the External Dose Pathway

The estimates of the dose to the intruder from external sources of radiation contain a significant amount of uncertainty surrounding the estimates. For the uncertainty analysis, the following potential sources of uncertainty or variability are identified:

1. There is a variation of dose due to gender, as compared to calculated. The error is assumed to be uniform, with a ±10% error. The magnitude of the estimate if based upon comparisons of adult sex-specific and hermaphrodite phantoms [Eckerman and Ryman, 1993]. Not included in this estimate is variation due to physical size, as this analysis is for an adult. NCRP Commentary #15 [NCRP, 1998] states that the dose to a baby is perhaps 20% higher than that received by an adult (primarily due to height). It is interesting to note that the corrections are not much different for children as compared to adults [NCRP, 1999].
2. The ratio of the effective dose as compared to the air kerma is about 80% for rotational exposures [NCRP, 1999]. This value is almost independent of energy.
3. There is uncertainty, due to Effective Dose versus Effective Dose Equivalent. FR #12 uses ICRP 26 tissue weighting factors. The fact that the older tissue weighting factors (ICRP 26) are used as opposed to ICRP 60 recommended values introduces an error of less than 10% [NCRP, 1999].
4. Variations in the estimate of the exposure time are also large. These include errors in the time spent outdoors (in the contaminated area), as well as time spent indoors. The uncertainty analysis is based upon the data from the EPA *Exposure Factors Handbook*.

10.3.2 Critical Parameters in the Radon Pathway

Radon risk estimates are seldom performed by calculating the dose from an exposure and then converting directly to risk. Instead, epidemiological data from miners are used to determine the actual risk from exposure. To provide an estimate of the dose received, the risk estimate is converted back to a dose. One salient issue when converting from risk to dose is the appropriate conversion factor to use. Radon and its progeny predominately affect only the lung. The inclusion of non-fatal contributions, and relative length of life lost, only reduce the fatality probability by about 5% [ICRP, 1990]. Additional detriments to other tissues of the body from radon exposure only increase the risk by about 2% [ICRP, 1993]. These differences between the fatal coefficient and the overall detriment are small enough to allow the use of the fatality coefficient for an overall measure of detriment. So, the risks are essentially the same for radon exposure, whether one chooses an overall health detriment or simply a fatal cancer coefficient.

The uncertainty for the radon estimates is as large as those for the groundwater portion of the analysis. Attachment 1 provides the results of the radon-related analysis modeled for uncertainty. Some sources of uncertainty, however, were not modeled and are discussed below:

- The radon emanation coefficient would be expected to vary from about 0.14 to 0.28, depending upon the soil type [Yu, et al, 1993]. This range of values is somewhat misleading for the LLRW facility, as up to 80% of the radium source term is in the form of discrete sealed sources encased in concrete. Such a sealed source would not be expected to have a significant emanation fraction for perhaps several thousand years. The effect of sealed sources after 500 years is not considered in the uncertainty analysis and will result in a high bias of results. The effective diffusion coefficient is dependent upon the type of soil, porosity, and percent moisture. The radon diffusion calculations relied upon Nuclear Regulatory Guidance 3.64. This guidance, as expected, is somewhat conservative. Other sources of models for the calculation of the radon flux differ by as much as 50% lower than the values used [Hart, et al, 1986]. This potential high bias due to the model is not considered in the analysis.
- Another source of uncertainty is the effective dose per unit exposure factor. Whether this value is derived based upon the energy deposited in the lungs or based upon the epidemiology of the miner studies, numerous uncertainties exist. For the lung, uncertainties exist as to the target cells of interest and the location. Uncertainties inherent in epidemiological modeling include lack of statistical size, adequate control groups, extrapolation from miners to home exposure conditions, adequate control for competing causes of cancer, etc. The range used for modeling is based upon the information provided by the EPA for their proposed drinking water rule [National Research Council, 1999].
- Estimates of the hours of occupancy indoors available in the literature range from about 50% to 100%. For this analysis, the data for the time spent indoors and outdoors are based upon the EPA *Exposure Factors Handbook*.

10.4 Uncertainty Associated with Radiation Dosimetry

The EPA *Radiation Exposure and Risks Assessment Manual* (RERAM) [U.S. EPA, 1996] provides a comprehensive list of the sources of uncertainty in radiation dosimetry. The uncertainties are due to the model itself (as a simulation of actual processes within a human body) and parameter variability caused by variation among individuals or measurement error. The sources of uncertainty listed by the EPA include (verbatim):

- Uncertainty in the formulation of the mathematical models for
  -deposition of activity in the lung and translocation of inhaled activity into blood,
  -translocation and absorption of ingested activity into the blood,
  -distribution and retention of activity from blood to various systemic organs and tissues, and

-calculation of the absorbed dose to an organ or tissue from activity in that and other organs and tissues;

- Uncertainty in the model parameters, including:
  -parameters in the biokinetic and dose models (e.g., GI absorption fraction, lung clearance class, organ deposition fractions and retention times, organ masses and geometries, etc.), and
  -anatomical and physiological data for characterizing the population of interest.

Dunning and Schwarz [Dunning and Schwarz, 1981] evaluated the uncertainty of estimates of dose to the thyroid from I-131, due to the variability of thyroid mass, uptake and retention of ingested iodine. Using Monte Carlo methods, they determined that the resulting frequency distributions are highly skewed log-normally-distributed, with a geometric standard deviation (GSD) of 1.8. Napier [U.S. DOE, 1998] interpreted these data for application to the uncertainty of all dose conversion factors and rounded the GSD to 2.[75] NCRP 129 [NCRP, 1999] evaluated available data for both inhalation and ingestion dose conversion factors (DCF) and found that the GSD ranged from 1.4 to 2.2 for inhalation conversion factors. The ingestion DCF uncertainty ranged from a GSD of 1.25 to 2.5, depending upon the radionuclide. Although this EIS analysis did not differentiate the uncertainty based upon pathway and radionuclide, a GSD of 2.0 for all radionuclides and pathways is viewed as sufficiently representative.

10.5 Uncertainty Associated with Risk Projection Models

NCRP Report 126 specifically addresses uncertainties in fatal cancer risk estimates induced by Low-Linear Energy Transfer (LET) radiation such gamma and beta radiation. The uncertainty in NCRP 126 is segregated into five general areas. The details of these parameters can be found in Attachment 1, the Uncertainty Parameters Table. The uncertainty for exposure to high LET radiation (alpha radiation) such as would result from exposure to radon, is considered in Section 10.3.2.

ICRP 65 [ICRP, 1993] qualitatively addressed the uncertainties associated with exposure to radon. Uncertainties for radon epidemiology are as follows:
- Statistical limitations related to the size of the exposed population, the projection model, and the exposure-response relationship
- Individual exposure estimates
- Appropriate control group for study
- Consideration of the different atmospheres for mines as compared to homes and the different atmospheres among mines
- The influence of non-radioactive ore dusts (where the epidemiological studies are conducted)
- Smoking habits
- Differences in follow-up periods for the studies conducted

[75] The GSD matches closely with the information recently published in NCRP 129, which recommends a GSD of 2.2 for most radionuclides.

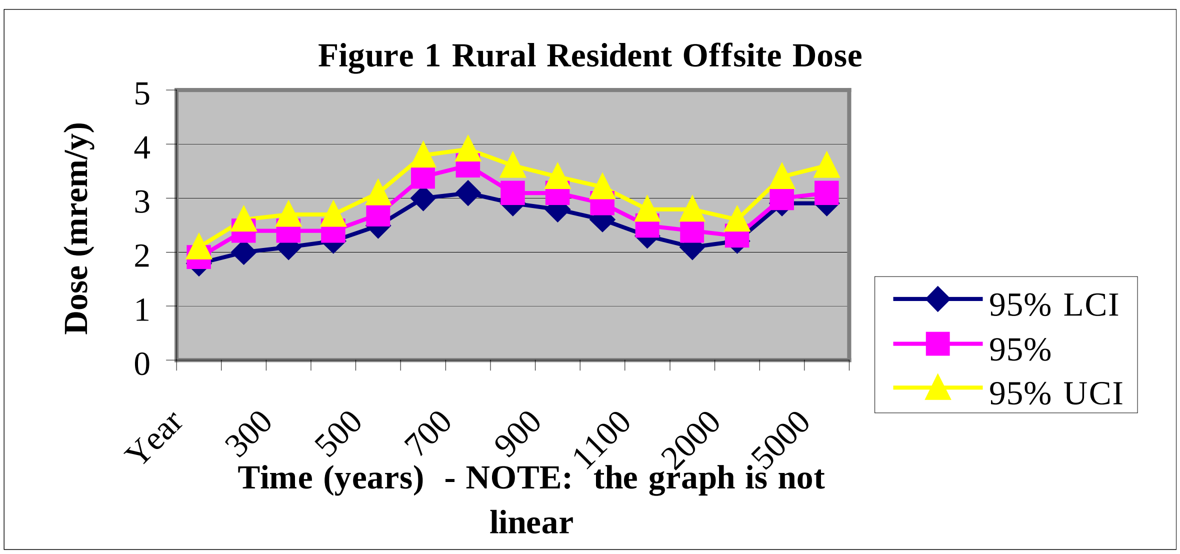
In spite of the large number of uncertainties associated with the radon epidemiology, it is widely viewed that the epidemiological basis for radon risk is more direct and involves less uncertainty than the indirect use of the epidemiology of low-LET radiation from the Japanese data.

10.6 Results

The results discussion, similar to the radiological assessment as a whole, is divided into onsite and offsite results. The results include estimates of the total range of dose and risk. The uncertainty analysis is evaluated for a silt/loam cover, which is similar to the Proposed, Thick Homogeneous Cover, and the Enhanced Covers. The uncertainty analysis also includes a clay layer similar to that used for the Enhanced Bentonite and Proposed Covers. The uncertainty analysis results are intended to broadly apply to any silt/loam cover. Although the final cover chosen for the site may or may not contain a clay barrier, conservative high bias remains in the radon uncertainty analysis such that the clay barrier would be expected to perform well without a clay layer.

10.6.1 Offsite Dose and Risk Distributions

Figure 1 shows the results of the 95% of the expected dose for the Offsite Rural Resident. The range of results are all within the 2 to 4-mrem bound, and indicate, based upon this analysis, that the single-point results reported in Chapter 5 are sufficiently conservative. As a reference, estimated single-point doses range from 2.7 mrem/y for the Asphalt Cover to 9 mrem/y for the Enhanced Synthetic and Thick Homogeneous Cover.[76] Figure 1 reveals a peak dose about 800 years. This peak is due to the contributions of Tc-99 and Cl-36. The increasing results near the 10,000-year point are a combination of I-129 and uranium (and progeny).



[76] As a reminder, the synthetic and homogeneous covers result in higher estimates doses for the single-point analysis, due to no credit being given to the synthetic barrier, and no clay layer present in the homogeneous cover.

Figure 2 is a frequency distribution of the results from the 800-year timeframe, the time location of the peak dose. The figure shows the expected dose on the X-axis versus the probability for a given dose on the Y-axis. The dose range extends from 0 to 8 mrem, with a most likely value (the mode) about 0.5 mrem/y, and a 95-percentile upper bound value of 3.6 mrem/y. Figure 2 is the result of a 2-dimensional simulation where the parameters distributions are segregated as either predominantly due to uncertainty, or due to variability.[77] Attachment 1 provides further information on all of the parameter values, their distributions, and associated references for the Monte Carlo analysis. The results from Figure 2 indicate that all of the expected single-point results for the various Enhanced and Thick Homogeneous covers are possible but are not likely events.

Figure 2 Rural Resident Offsite Dose

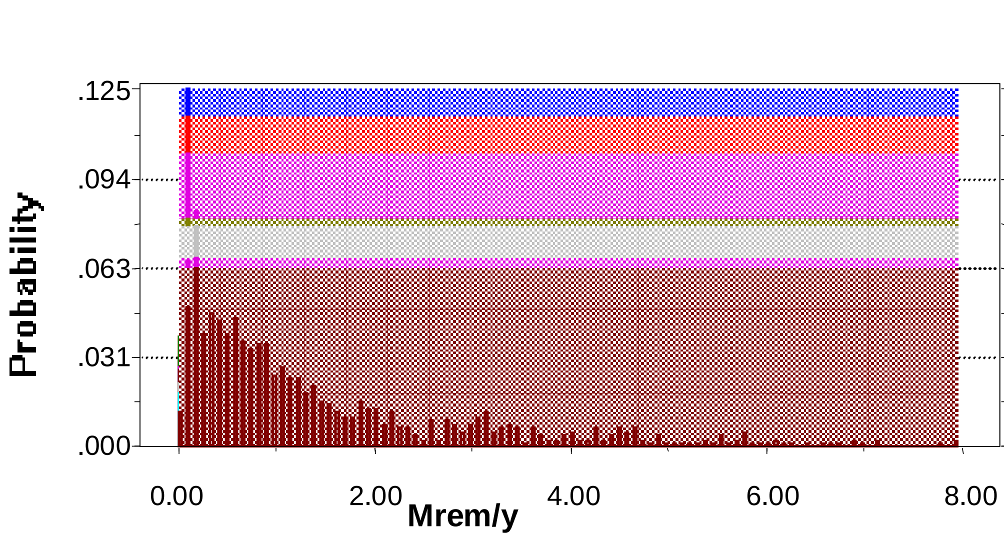
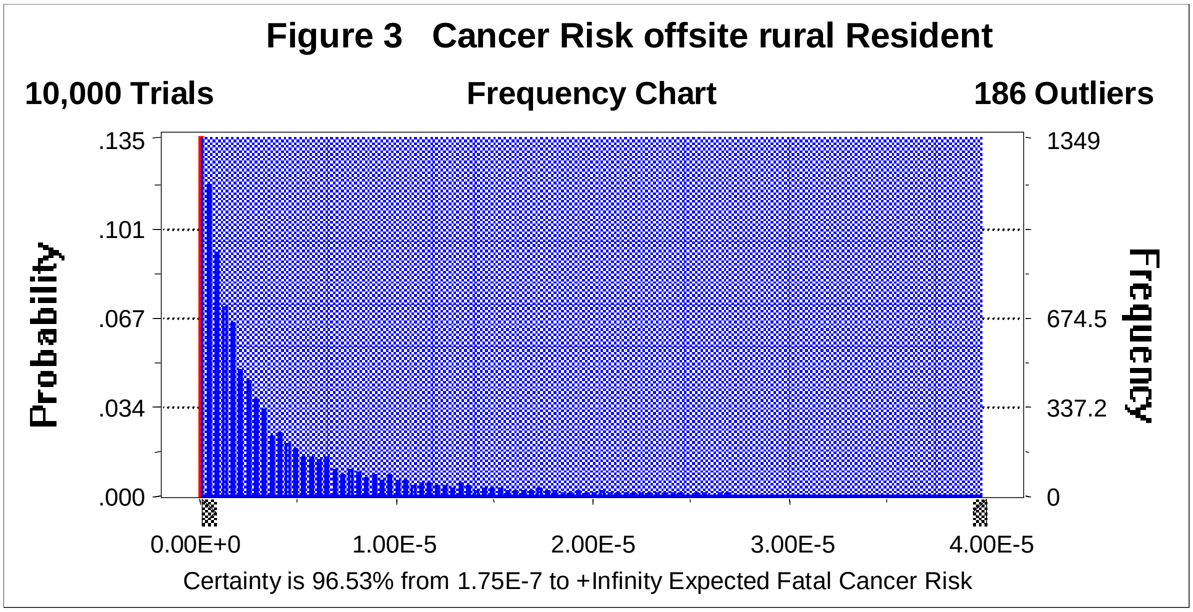


Figure 3 contains the offsite cancer risk distribution for the rural resident adult. The log normal distribution has a 95-percentile value of approximately one in 45,000. The median value, however, is roughly one in 500,000, and the most likely cancer risk for offsite exposure from the site is less than one in 1,000,000. The cancer risk estimates are shifted to the lower risk bounds as the analysis takes into consideration the U.S. statistics on individuals living in the same location [U.S. EPA. 1997]. The amount of time spent in a given location, combined with a low modal value for dose received to the offsite adult, results in the very low distribution of expected risk.

[77] The possibility for increased complexity in the modeling of uncertainty and variability is almost without bounds. Many parameter distributions contain both uncertainty and variability, and it is possible, assuming sufficient data exist for the complexity, to model parameters for both. In an effort to accurately model the various distributions as simplistically yet as accurately as possible, the assumption was made that a given parameter distribution is dominated by either variability or uncertainty, but not both.

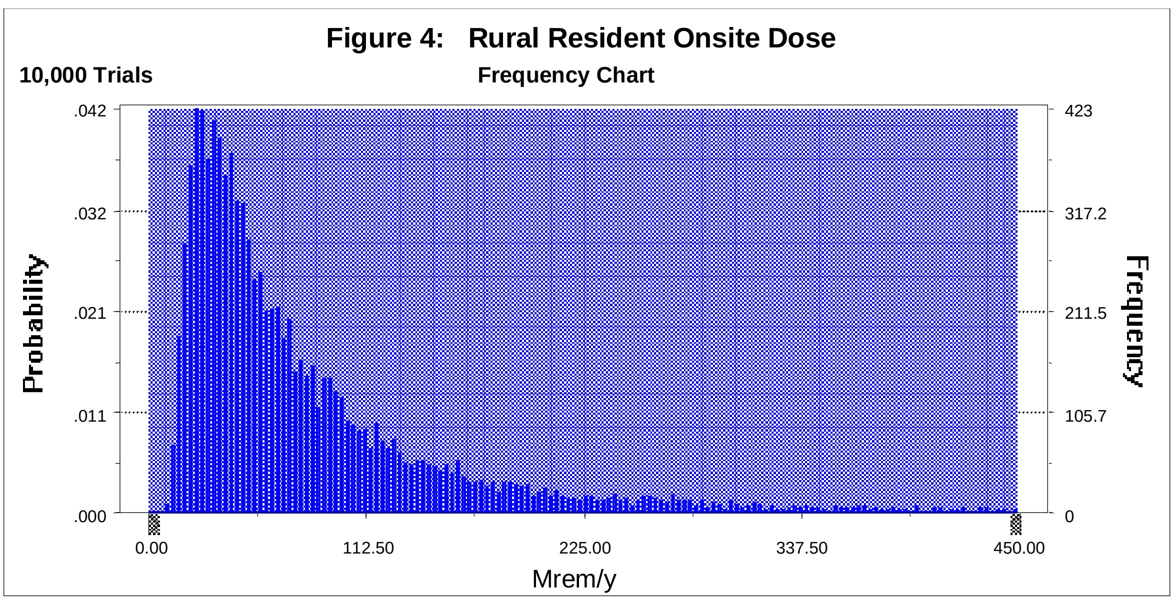


10.6.2 Onsite Dose and Risk Distributions

Figure 4 displays the results of the dose distribution for the Rural Resident Adult. The

95-percentile value is 290 mrem/y, which is in strong agreement with the estimated values from the single-point doses reported in Chapter 6 for the Enhanced Bentonite and Proposed Covers. Other statistics for the onsite distribution are:

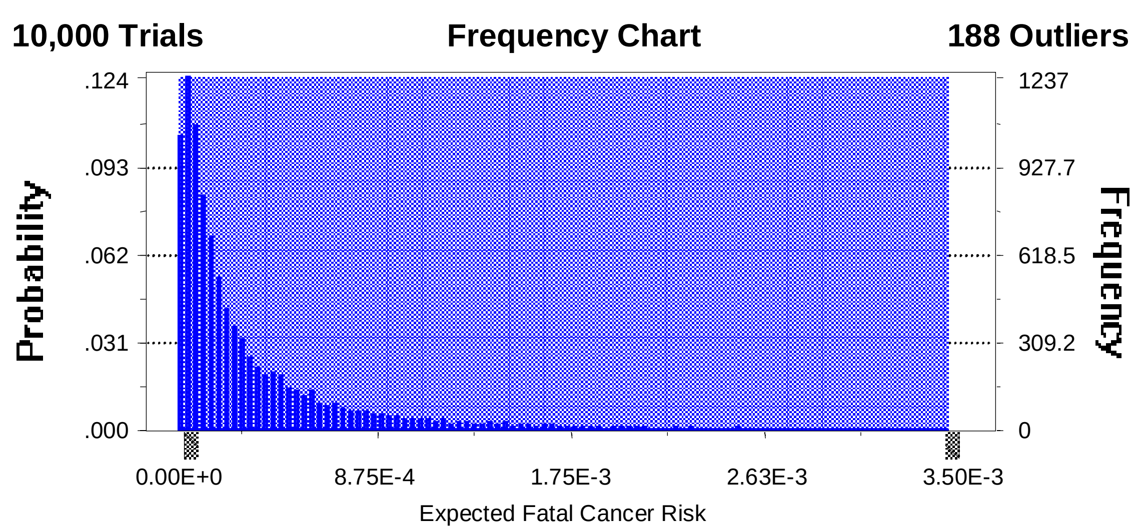
- Mode ≅ 30 mrem/y
- Median = 60 mrem/y
- Mean = 100 mrem/y



The large variation between an upper bound estimate of 290 mrem/y and the most likely value of 30 mrem/y indicates the great variation in the estimated dose for an intruder that is due in large part to lifestyle assumptions and patterns. Simply put, an intruder who spends most of the day inside the house, consumes a large amount of drinking water every day, and grows a majority of his/her own food, would receive a significantly higher dose than an individual living at the same location who spends a significant amount of time working elsewhere and grows little food locally. This type of variability greatly influences the final results.

The onsite risk distribution is detailed in Figure 5. The 95-percentile estimated risk is approximately one in 550. This value is less than the single-point estimates for all Enhanced covers and can be attributed to account for the decreased likelihood of living in a single location for 30 years. Other information for the onsite risk distribution is:
Mode ≅ one in 500,000
Median = one in 5,500
Mean = one in 2,000

Figure 5 Rural Resident Onsite Cancer Risk



10.7 CONCLUSIONS

The intent of this uncertainty analysis is to provide an estimate of the overall range and distribution of the dose and expected cancer endpoints. In doing so, evaluating the strength and conservatism of the single-point dose and risk estimates for the rural resident is possible. The results indicate that the single-point estimates are generally greater than the 95-percentile values (the intended target endpoint). The analyses also confirm that the data is a positively skewed, log-normal distribution. Expected exposure for individuals would be less than those predicted from the single-point estimates.

Detailed results in Figures 2 through 5 only provided results for the peak time period identified in Figure 1. The peak 800-year time period median value for the rural resident offsite dose is less than 1 mrem/y. The expected median risk is approximately one in

500,000. The median dose for the rural resident intruder is approximately 60 mrem/y. The median onsite risk is approximately one in 5,500. Table 55 summarizes the salient statistical information for the onsite and offsite dose and risk estimates.

Table 55 Rural Resident Adult Summary Uncertainty Results

	Mode	**Median**	**Mean**	**95%**
Offsite Dose (mrem/y)	0.5	0.7	1.1	3.6
Offsite Risk (fatal cancer)	<1 in 1,000,000	1 in 500,000	1 in 170,000	1 in 45,000
Onsite Dose (mrem/y)	30	60	100	290
Onsite Risk (fatal cancer)	Approx. 1 in 500,000	1 in 5,500	1 in 2,000	1 in 600

There are a number of factors that are only qualitatively included in the uncertainty analysis. Two in particular are: (1) uncertainties associated with model limitations both in the radon analysis; and, (2) in radiation dosimetry in general. Not including model uncertainty for the radon analysis leads to a high bias in the results. The impact of the radiation dosimetry uncertainties not defined has an unknown impact on the final results.

The Tc-99 and I-129 source term is biased high by at least a factor of ten. Although this correction would have a significant impact on predicted dose and risk for time periods less than 3,000 years, it would have a smaller impact on the 10,000-year estimates, as the uranium (and progeny) source term dominate the results. The end result of including the Tc-99 and I-129 source term bias in the uncertainty analysis is that the time period for peak impact moves closer to 10,000 years, but the overall estimates would only be slightly smaller; perhaps by 30%.

The uncertainty analysis results indicate that the results reported in Chapters 5 and 6 of this Appendix are sufficiently conservative. The dose and risk estimates for the maximally exposed individual for the single-point estimates is slightly conservative, while the most likely dose and risk for the average member of the public is significantly less than the upper bound dose reported.

11.0 RADIOLOGICAL ASSESSMENT CONCLUSIONS

General Statement

This Radiological Risk Assessment has estimated the impact of site closure for a variety of potential covers and closure dates. The results are discussed in terms of expected dose as well as fatal cancer probability. These two expressions of impact, the expected or estimated dose and the corresponding fatal cancer probability, are common methods for expressing the results from radiological exposures. It is also common, however, for chemical risk assessments to express the expected impact in terms of cancer morbidity and mortality, which includes both fatal and non-fatal cancers. In order for the results from both a chemical source and a radiological source to be comparable, the risks units must be equated to the same endpoint.

The radiological results reported in this assessment can be expressed in terms of an overall measure of harm or detriment. This overall measure of detriment includes both fatal and non-fatal cancers, the probability of severe hereditary effects, and the relative length of life lost (due to fatal cancers) [ICRP, 1990]. When taking into consideration all of the additional factors other than the probability of fatal cancers, the risk estimates are increased by approximately 50%.[78] This measure of overall detriment is more comprehensive than that typically used in chemical risk assessments, that includes only the probability of fatal and non-fatal cancers. It is important to point out that exposures of some chemicals can have genetic impacts as well (commonly called teratogenic agents). Such exposures for chemicals must be estimated on a contaminant-specific basis and may not be included in the reported risk from a chemical exposure.

Considering the potential errors in comparing exposures of radiological and chemical sources and the small estimated chemical contribution from the waste site, the decision was made to report the results from the radiological exposures in terms of the probability of fatal cancer, while providing the method for estimating the overall detriment. Summation of sources of non-radiological exposures (within the 200 areas) with radiological exposures can be performed, but these additions should be carefully reviewed to ensure that the endpoint expressed for each exposure source is the same.

Specific Summary

Included in this analysis is a single-point estimate of the expected dose and risk to an individual, based upon an assumed lifestyle. Due to the large uncertainties in contaminant movement in the groundwater, future land use, and lifestyles of individuals, these single-point estimates are shown to be conservative and are only intended to serve as predictive estimates for the individuals in the scenarios created.

The groundwater concentrations served as the initial basis for a majority of the dose and risk estimates. The subsequent environmental (such as soil to plant transfer

[78] More specifically, the dose-to-risk conversion factors used in the tables in Chapter 5 would change from 0.0005/Rem to 0.00073/Rem.

factors) and individual parameters (such as time spent indoors, drinking water rates, etc.) were also chosen to provide conservative yet realistic estimates of overall detriment.

The results of the analysis for the onsite and offsite individuals indicate that there are several covers that perform quite well in limiting both the infiltration of water and the emanation of gases. By limiting the infiltration and gas emanation, these covers effectively limit the dose received by an individual. All of the Enhanced Covers and the Thick Homogeneous Covers meet the criteria of performing well for both onsite (via the groundwater pathway) and offsite (via both the groundwater and air pathway) scenarios. The Enhanced Bentonite 2000 Cover performs well and is essentially an option to safely close the site now. The Proposed Cover meets the regulatory criteria for all scenarios, with a slightly greater estimated dose than the Enhanced Covers. The Filled Site Cover is identical to the Proposed Cover and results in a higher dose estimate, due to the greater amount of waste allowed by not closing the site until the year 2215. The Site Soils Cover is an estimate of the impact from the site, without attempting to limit water infiltration or gas emanation through a better designed cover with barriers included. Please review Sections 5.9 and 6.9 for a more thorough discussion of the predicted impacts from the covers. The groundwater modeling discussion in the groundwater appendix will also provide more information about the suitability and groundwater results of the covers.

Chapter 7 applies MTCA parameters and scenarios to the various alternatives. The onsite intruder results would apply if the point-of-compliance were chosen as an onsite location. If an alternative point-of-compliance were chosen, such as the fenceline boundary, then the results calculated for the offsite individual would apply. Comparison of the results to the MTCA acceptable risk of 1 in 100,000 shows that all of the results are greater than the acceptable free-release criteria and would indicate the need for some type of institutional controls to limit the dose received by individuals. As of the publication of this EIS, there are no plans to invoke MTCA at the disposal site, so these results are for informational purposes only.

Chapter 8 of this report presented the ecological risk analysis for herbivores, carnivores, and vegetation expected on or near the disposal facility. The analysis indicated that in all cases, the projected dose to any plant or animal is less than the IAEA limit of 0.1 rad/day. The maximum predicted dose is to the pocket mouse of 0.03 rad/day.

Chapter 9 analyzed the impact of varying volumes of NARM waste disposed each year. The results are presented for the rural resident only and clearly show that NARM disposal has an impact to the onsite intruder through the increased radon gas contribution. The offsite individual is subject to a somewhat greater dose for higher volumes of NARM. For the Enhanced Alternative Cover, this contribution amounts to a few additional mrem/y.

Chapter 10 analyzes the uncertainty for the rural resident adult. The uncertainties included are provided in Attachment 1. Further uncertainties that are only qualitatively included are discussed in the text of this chapter. The results of this analysis show that the single point estimates of Chapter 5 and 6 for offsite and onsite dose and risk estimates are sufficiently conservative and tend to over-estimate the 95% target dose and risk. The most likely dose for the onsite and offsite rural resident is about a factor of 10 less than the 95% estimates. The most likely risk exposures estimated range from 20 times less than the 95% for the offsite rural resident, to several thousand times less for the onsite rural resident.

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TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
Irrigation Rate - leafy vegetables, fruit, and grain	L/m²d	Triangular	5.00		4.50	5.00	5.50	U	[Schreckhise, R.G.,et.al, 1993] for mean, [U.S.DOE, 1996] for uncertainty	
Irrigation Rate - non leafy vegetables	L/m²d	Triangular	5.55		5.00	5.55	6.10	U	[Schreckhise, R.G.,et.al, 1993] for mean, [U.S.DOE, 1996] for uncertainty	
Irrigation Rate - grasses, stored hay	L/m²d	Triangular	6.60		5.94	6.60	7.26	U	[Schreckhise, R.G.,et.al, 1993] for mean, [U.S.DOE, 1996] for uncertainty	
Weathering Constant	/d	Triangular			0.04	0.05	0.14	U	[Till, J.E. and Meyer H.R., 1983]	
Plant Yield - leafy vegetables, fruit	kg/m² wet weight	Normal	2.00	0.20	1.40	2.00	2.60	U	[Kennedy, W.E.Jr., and Strenge, D.L., 1992] for mean values, [Till, J.E. and Meyer, H.R., 1983] for uncertainty (adapted from forage crops)	
Plant Yield - non leafy vegetables	kg/m² wet weight	Normal	4.00	0.40	2.80	4.00	5.20	U	[Kennedy, W.E.Jr., and Strenge, D.L., 1992] for mean values, [Till, J.E. and Meyer, H.R., 1983] for uncertainty (adapted from forage crops)	
Crop growing periods	need data									Although varying, the contribution to uncertainty regarding uptake is small
runoff coefficient	unitless	Triangular	0.20		0.10	0.20	0.30	U	[Yu, C., Zielen, A.J., Cheng, J.J., Yuan, Y.C., Jones, L.G., LePoire, D.J., Wang, Y.Y., Loureiro, C.O., Gnanapragasam, E., Faillace, E., Wallo III, A., Williams, W.A., and Peterson, H., 1993]	
rainfall	m/y	Triangular	0.16		0.10	0.16	0.20	U	[U.S.DOE, 1998]	
hydraulic conductivity	m/y	Triangular			200.00	333.00	5500.00	U	Source?	
plant contaminated zone thickness	m	Triangular			0.08	0.15	0.23	U	[U.S.DOE, 1996]	
mass loading factor for resuspension to edible portions	g soil/g dry plant	Triangular			0.01	0.10	0.26	U	[Kennedy, W.E.Jr., and Strenge, D.L., 1992] for mean values, [Till, J.E. and Meyer, H.R., 1983] for uncertainty (adapted from forage crops)	
Wet to dry conversion factor, leafy vegetables	g dry weight/g wet weight	Triangular	0.07		0.05	0.07	0.14	U	[U.S. EPA, 1997]	John Till's book, Radiological Assessments provided similar data for all wet to dry conversion

TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
										factors
Wet to dry conversion factor, non leafy vegetables	g dry weight/g wet weight	Triangular	0.11		0.04	0.11	0.41	U	[U.S. EPA, 1997]	
Wet to dry conversion factor, fruits	g dry weight/g wet weight	Triangular	0.20		0.08	0.20	0.26	U	[U.S. EPA, 1997]	
Wet to dry conversion factor, fruits	g dry weight/g wet weight	Triangular	0.22		0.18	0.22	0.25	U	[U.S. EPA, 1997]	
Leafy vegetables intake rate - homegrown consumption only	kg/y	Log-normal			5% - 0.015		95% - 4	V	[U.S. EPA, 1997]	Correlated with non leafy vegetable consumption - 0.7, P99 - 17 kg/y
Non Leafy vegetables intake rate - homegrown consumption only	kg/y	Log-normal			5% - 0.07		95% - 18.6	V	[U.S. EPA, 1997]	P99 = 79.3 kg/y
Fruit intake rate - homegrown consumption only	kg/y	Log-normal			5% - 0.082		95% - 23	V	[U.S. EPA, 1997]	correlated with vegetable consumption - 0.6, P99 = 125 kg/y
Beef intake rate - homegrown consumption only	kg/d	Log-normal			5% - 0.0011		95% - 0.131	V	[U.S. EPA, 1997]	p99 = 0.2 kg/d, fraction consuming 0.0503
Dairy intake rate - homegrown consumption only	l/d	Log-normal			5% - 0.126		95% - 2	V	[U.S. EPA, 1997]	correlated with vegetable consumption - 0.6
Poultry intake rate - homegrown consumption only	kg/d	Log-normal			5% - 8.9e-04		95% - 0.106	V	[U.S. EPA, 1997]	correlated with vegetable consumption - 0.6
Egg intake rate - homegrown consumption only	kg/d	Log-normal			5% - 0.0144		95% - 0.952	V	[U.S. EPA, 1997]	correlated with vegetable consumption - 0.6
Drinking Water Intake Rate	L/d	Log-normal			5% - 0.5		95% - 2.5	V	[U.S. EPA, 1997]	Lower bound truncated at 0.5 l/d
Effective days spent drinking water at home	d/y	Log-normal			5% 147		95% - 486	V	[U.S. EPA, 1997]	Upper bound truncation at 365 days
Soil Ingestion	mg/d	Log-normal	43.00	41.00				V	[Hamed M.M., and Bedient, P.B., 1997]	Upper bound truncation at 99%

TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
Soil Exposure Frequency	d	Triangular			180.00	345.00	365.00	U	[U.S. DOE, 1996]	Based upon Native American exposure frequency
Total Soil Porosity		Uniform			0.30		0.46	U	[Yu, C., et.al., 1993]	Primarily sandy soil
Distribution Coefficient - Cl-36, Tc-99	cm^3/g	custom			-0.07	0.00	0.60	U	[Kincaid, C.T., et.al., 1998] for data range	Shape and modified range of curve based upon input from Fayer [Fayer, M.J., 1999]
Dose Conversion Factor -Tc-99	Sv/Bq	Log-normal	GM = 6.37 E-10	GSD = 2	1.60E-10		2.54E-09	V	[Dunning, D.E.Jr and Schwarz, G., 1981],[U.S. DOE, 1998]	Napier increased the GSD of 1.8 in Dunning and Schwarz to 2 to account for uncertainty on increased variability for different organs
Dose Conversion Factor -Cl-36	Sv/Bq	Log-normal	GM = 9.25 E-10	GSD = 2	2.30E-10		3.70E-09	V	[Dunning, D.E.Jr and Schwarz, G., 1981],[U.S. DOE, 1998]	Napier increased the GSD of 1.8 in Dunning and Schwarz to 2 to account for uncertainty on increased variability for different organs
Soil to Plant Concentration Factor - leafy vegetable	pCi/g dry plant/pCi/g soil	Log-normal	210.00	40.00	5.00		430.00	U	[IAEA, 1994]	Upper bound based upon mass balance calculations
Soil to Plant Concentration Factor - grains	pCi/g dry plant/pCi/g soil	Log-normal			5% - 0.07		95% - 3.7	U	[IAEA, 1994]	
Soil to Plant Concentration Factor - grasses, stored hay, forage	pCi/g dry plant/pCi/g soil	Log-normal	GM = 76	GSD = 2.3	5.00		640.00	U	[IAEA, 1994]	Upper bound based upon mass balance calculations
Epidemiological Uncertainty for risk estimates		Normal			5% - 0.8		95% - 1.3	U	[NCRP, 1997]	
Over/under reporting of deaths		Normal			5% - 1.02		95% - 1.18	U	[NCRP, 1997]	
Dosimetric Uncertainty for risk estimates		Normal			5% - 0.69		95% - 1	U	[NCRP, 1997]	
Transfer of risk between populations		Log-normal			5% - 0.7		95% - 1.65	U	[NCRP, 1997]	
Lifetime risk projection		Triangular			0.50	1.00	1.10	U	[NCRP, 1997]	

TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
uncertainty										
Extrapolation to Low Dose or dose rate		Custom			1.00		5.00	U	[NCRP, 1997]	
Unknown uncertainty on cancer risk estimates		Normal			5% - 0.5		95% - 1.5	U	[NCRP, 1997]	
radon emanation coef		Triangular			0.14	0.21	0.28	V	Yu,C. Loureiro, C. Cheng. J.-J. Jones, L.G. Wang, Y.Y. Chia, Y.P. and Faillace, E., 1993	Summary of ranges reported from various sources
Water Saturation fraction - tailings (waste) RAETRAD Table 3.3		Triangular			0.04	0.05	0.09	U	Nielson, K.K., Rogers, V., and Rogers, V.C. 1993	see comment in corner
Water Saturation Fraction - clay layer (RAETRAD Table 3.3)		Triangular			0.4.	0.55	0.80	U	[Nielson, K.K., Rogers, V., and Rogers, V.C. 1993] and [Terzaghi, K. and Peck, R.B., 1967]	see comment in corner
Water Saturation Fraction - cover (RAETRAD Table 3.3)					Same as Waste Materia l					Material for cover and waste fill are considered the same
dry density cover	g/cm^3	Triangular			1.20	1.50	1.60	U	Yu,C. Loureiro, C. Cheng. J.-J. Jones, L.G. Wang, Y.Y. Chia, Y.P. and Faillace, E., 1993	
dry density waste	g/cm^3	Triangular			1.10	1.30	1.50	U	US Ecology, 1996 for mean	Estimate of uncertainty of mean
Building height	m	Truncated Normal	2.50	0.25	2.50			V	Mean based upon EPA, 1997. Distribution estimated	
Building area	m^2	Normal	150.00	12.00				V	EPA, 1997	
emanation reduction through concrete		Triangular			0.05	0.10	0.20	V	Landman, K.A., and Cohen, D.S., 1983 and Nielson, K.K., Rogers, V., and Rogers, V.C..,1993	RAETRAD used to estimate the emanation through concrete via modeling
ventilation rate	s-1	Lognormal	GM = 1.31 E-	GSD = 2.1				V	EPA, 1997	

TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
			04							
home adjustment factor (HPS 66(6), p699-706 1994)		Triangular			0.20	0.38	0.60	V	[Marcinowski, F., Lucas, R.M., and Yeager, W.M., 1994] and [Fisher, E.L. Field, R.W. Smith, B.J. Lynch, C.F. Steck, D.J. and Neuberger, J.S., 1998]	Variability depends upon home type which is somewhat dependent upon geographic location
hours of occupancy in residence	Hours	Lognormal	GM = 5780	GSD = 1.2				V	EPA, 1997	
Effective dose per unit exposure	mrem/WLM	Lognormal	GM = 750	GSD = 1.3	465.00		1100.00	U	National Research Council, Risk assessment of Radon in Drinking Water. National Academy Press. 1999	Also values from ICRP 65, other recent analysis as shown in ICRP 60
External dose uncertainty due to gender		Triangular			0.90	1.00	1.10	V	Eckerman, K.F. and Ryman, J.C. 1993	Eckerman uses a hermaphrodite phantom that causes some variation to specific gender
uncertainty in external dose due to calculated versus actual field conditions					0.77	0.81	0.93	U	Eckerman, K.F. and Ryman, J.C. 1993	Based upon Table II.16, ground level effective dose equivalent as compared to normal rotational beam exposure
Hours outside, near home	hr	Lognormal			5% - 61		95% 2560	V	EPA, 1997	Table 15-120
Indoor to outdoor ratio shielding effect		Triangular			0.20	0.40	0.50	V	NCRP, 1988	Data from Burson and Profio, 1977 for wood framed houses w/o basements, [Miller, 1992]
Exposure Duration	y	Lognormal			5% - 2		95% - 41	V	EPA, 1997	P99.9 = 75 years
Indoor dust loading	g/m3	Triangular			5 E-07	7 E-06	7 E-06	U	Thatcher, T.L. and Layton, D.W. 1995	
Outdoor dust loading	g/m3	Uniform			9 E-06		7 E-05	U	Kennedy, W.E.Jr., and Strenge, D.L., 1992	
Uniformity of surface contamination from well material		Uniform			0.10		1.00	U	Professional judgement	Based upon suitability of well material for use as surface soil
Groundwater Concentration	pCi/l	Custom							Art Rood, INEL	500 groundwater realizations were created

TABLE 1: UNCERTAINTY PARAMETERS

Parameters	Units	Distribution	Mean	Standard Deviation	Min	Mode	Max	Source of variability (V) or Uncertainty (U)	Source	Comment
										for each radionuclide

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APPENDIX III

Groundwater Pathway Analysis for the Commercial Low-Level Radioactive Waste Disposal Site Richland, Washington

Washington State Department of Health
Division of Radiation Protection

GROUNDWATER PATHWAY ANALYSIS

For The

COMMERICAL
LOW-LEVEL RADIOACTIVE WASTE DISPOSAL SITE
RICHLAND, WASHINGTON

Maxine Dunkelman

September 5, 2000

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ATTACHMENTS

1.0 Introduction

The Washington State Department of Health (WDOH) is currently formulating an Environmental Impact Statement (EIS) for the US Ecology Low-Level Radioactive Waste (LLRW) Facility, located on the U.S. Department of Energy (DOE) Hanford Reservation near Richland, Washington. The EIS compares various alternative covers and times of closure for the facility. This report describes WDOH's computer modeling effort to predict what concentrations of radionuclides may be released into the groundwater from various alternative cover designs, as described in EIS Section 3, "Description of Pending Actions and Alternatives." Deterministic computer modeling was augmented with a limited stochastic uncertainty analysis**.**

The groundwater pathway conceptual model consists of the following stages:

- steady-state infiltration[1] of precipitation through the vegetated cover
- first-order leaching of radionuclides in the waste trench unless the solubility of the radionuclide is exceeded. If such is the case, then the leachate assumes a radionuclide concentration equivalent to the radionuclide solubility limit.
- one-dimensional advection and dispersion of radionculides in pore water downward through the vadose zone
- pore velocities in the vadose zone are controlled by natural recharge and not infiltration through the cover
- vadose zone pore water reaches the aquifer and mixes in an area defined by the area of the covered waste trenches
- the aquifer is assumed to have steady-state unidirectional flow in an isotropic homogeneous medium of infinite lateral extent and finite thickness
- water entering the aquifer from below the waste trenches is insignificant compared to the flow within the aquifer
- radionuclides mix vertically in the aquifer in a thickness defined by a typical well screen.

This well water is then utilized by farmers for such purposes as drinking, irrigating, and watering farm animals, as described in Thatcher et al, 2000, *Radiological Assessment for the Commercial Low-Level Radioactive Waste Disposal Facility, Richland, Washington*. Thatcher et al, 2000, reports the resulting radiological doses for both deterministic and uncertainty analyses described here.

This report describes:

- selection of nuclides to be modeled for groundwater transport
- deterministic computer modeling estimation of infiltration rates of the various alternative covers
- deterministic computer modeling of contaminant transport along the groundwater flow pathway, for each alternative cover
- input parameter values for deterministic runs
- deterministic results: predicted concentrations of key nuclides in the well water
- uncertainty analysis.

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[1] The usage of the terms, "infiltration," "recharge," and "percolation" according the Dictionary of Geological Terms (Dictionary of Geological Terms, 1976):

"Infiltration" connotes flow into soil.
"Percolation" connotes flow through soil.
"Recharge" connotes flow into the saturated zone.

In this document, the above definitions are applied where practical; "infiltration" applies to flow into and through the cover; "percolation" applies to the infiltration/percolation parameter "PERC" in the model GWSCREEN.

The computer codes used by WDOH are: UNSAT-H (Fayer and Jones, 1990) and GWSCREEN (Rood, 1994 and Rood, 1998). The UNSAT-H code was used to estimate the infiltration rates for the various alternative covers. The GWSCREEN code, version 2.4a, was used to screen for significant radioactive contaminants. GWSCREEN, version 2.5, [2] was used to simulate the transport of radioactive contaminants from the waste trenches, through the vadose zone, into the groundwater, and then into the well. GWSCREEN was used for both the deterministic modeling and the uncertainty analysis. For the deterministic modeling, GWSCREEN 2.5 was applied to various alternative infiltration rates (including those predicted by UNSAT-H) to provide predicted concentrations of radionuclides in the well water for each alternative cover design. The alternative covers modeled, and their respective closure dates are:

Alternative Description	**Final Closure Date**
Proposed Action: USE Cover	Year 2056
Filled Site Alternative: USE Cover	Year 2056 or 2215
Site Soils Cover	Year 2000
Thick Silt Homogenous Cover	Year 2056
Enhanced Designs:	Year 2056
Enhanced Asphalt Cover	
Enhanced Synthetic Cover	
Enhanced Bentonite Cover	
Immediate Closure Alternative: Enhanced Bentonite Cover	Year 2000

Year 2000 closure dates represent alternatives with less waste disposed than do later dates**.** The filled site alternative is the alternative considering additional waste being disposed at the facility.

GWSCREEN 2.5 was used in the uncertainty analysis to predict concentrations based on stochastic modeling for the site soils cover and for an enhanced cover (a composite of the enhanced covers and the thick silt homogenous cover), both for the year 2056.

[2] GWSCREEN 2.5 became available after this modeling projected was underway.

2.0 Development of the Conceptual Model: Key Assumptions

Key assumptions for the overall groundwater pathway conceptual model are listed below, each followed by a description of the implication for computer modeling. Assumptions specifically related to infiltration through the cover are covered in Section 4, “Deterministic Modeling: UNSAT-H Computer Code.” Assumptions specifically related to groundwater flow and contaminant transport modeling are covered in Section 5, “Deterministic Modeling: GWSCREEN Computer Code Estimates of Groundwater Concentration and Travel Time.”

- All of the waste was disposed of at one time: No credit is taken for decay except during transport in the vadose and saturated zones.[3]

- All of the waste is available for transport through the vadose zone to the saturated zone: No credit is taken for the waste package or the waste form.

- The final cover is in place: The thirty-odd year period that the site has been operating, without a final cover and with a lower inventory, was not modeled.[4]

- The cover affects the water movement through the waste trench, but has no impact on water movement in the vadose zone under the trenches: No credit is taken for the covers’ ability to dry out the vadose zone. The vadose zone under the trenches has the same hydrologic characteristics as the vadose zone away from the disposal area where the surface is undisturbed and has remained vegetated.[5]

- The cover does not fail *over time:* For deterministic modeling, the same percolation *rate* is used for all time frames. For the uncertainty analysis, the same *range of percolation rates* are used for all time frames. The *range of percolation rates* reflect uncertainty in the long-term performance of the cover.[6]

- The well is located at the downgradient edge of the facility: The downgradient edge of the facility is the point of maximum concentration accessible by an individual living offsite and is essentially also the maximum for an onsite individual.[7]

[3] Credit was taken for decay for tritium for the time period between disposal and site closure.
[4] It is expected that the amount of waste that has been mobile during this first 30 years of operation is minimal given packaging and waste form requirements, the general dryness of the area, and the lack of evidence in the groundwater wells of transport to the saturated zone. This simplification of ignoring the years of operation without a final cover is in the process of being verified by a vadose zone monitoring program. Results from this monitoring program will be used to check this and other modeling assumptions and simplifications. In any case, the purpose of the modeling is to compare the concentrations of radionuclides in groundwater due to that cover, not due to the period before the cover was in place.
[5] For all covers, except the site soils cover, this assumption is conservative. The site soils cover would actually increase the moisture in the vadose zone, not decrease it.
[6] Variances such as degradation of the cover or changes in vegetation are modeled for all time frames and are not correlated to particular time periods.
[7] The distance from the edge of the waste trench to the edge of the site is negligible; negligible dispersion or decay would occur.

3.0 Selection of Nuclides Modeled

An initial set of radionuclides was selected for groundwater pathway modeling if (1) they have at least a minimal inventory (generally of around 1 curie or more), (2) they have half-lives that are about 100 years or greater[8], and (3) they travel via the groundwater pathway as opposed to the air pathway.[9,10] A few other nuclides (i.e., tritium and Sr-90) were also included in the modeling if they were of interest in generic modeling studies or have been commonly modeled or sampled at similar facilities.

These initial nuclides were then modeled using GWSCREEN, Version 2.4a, with an infiltration rate of 5.1 mm/year (0.2 inches/year) to determine which nuclides had an impact on dose.[11] The infiltration rate of 5.1 mm/year (0.2 inches/year) was chosen, as it is substantially greater than the infiltration rate expected through the proposed cover.[12] Radionuclides selected for this first round of modeling, and their source terms, are listed in Table 1.

The nuclides that did impact dose were Cl-36, I-129, Tc-99, U-235, and U-238. These nuclides where then further modeled with GWSCREEN 2.5 to predict groundwater concentrations for the 5 cover designs and 3 closure dates. The cover designs were simulated by imposing an infiltration rate; the closure dates were simulated by imposing the current source term (year 2000) or an increased source term (year 2056 or year 2215).

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[8] The 100-year half-life was chosen based on travel times of 10 half-lives occurring before the radionuclide would enter the aquifer. The travel time of roughly 1000 years was calculated both by US Ecology in their Closure Plan performance assessment, and by early runs with GWSCREEN 2.4 (assuming no adsorption (i.e., Kd=0) and no dispersion (not yet a feature of the code).

[9] The site has several hundred different radionuclides and isotopes disposed of at the site. Records of the complete inventory are available from the Washington Department of Health.

[10] Carbon-14 was modeled as part of the gaseous release pathway. Because C-14 provides a higher dose through the air pathway than the ground water pathway, all C-14 was assumed to go through the air pathway instead of splitting C-14 between the two pathways (Dunkelman et al, 1999).

[11] During this early screening modeling, the infiltration rate modeled was imposed on both the waste trenches and the unsaturated zone beneath the trenches; i.e., the amount of moisture that *infiltrated* completely through the cover was assumed to be the amount of moisture that *percolated* all the way to the groundwater as *recharge*. This conceptual model was modified in later modeling, as described in the Conceptual Model Section of Attachment 1, “Further Evaluation of Groundwater Concentrations for Different Covers.”

[12] The initial nuclides were also screened with an infiltration rate of 51 mm/year (2 inches/year). With the exception of tritium, the list of radionuclides of concern remained the same. Given an infiltration rate of 51 mm/year, or about one third of the annual rainfall, tritium was predicted to enter the groundwater table within decades after disposal; in other words, the current time frame. Because this conservative infiltration rate implies a current time frame, tritium migration is better investigated by the ongoing, onsite hydrologic investigations as opposed to projections from modeling with the attendant simplifying assumptions that no containment is provided by waste packaging or waste form at modeling-year zero. Note that none of the alternatives has an infiltration rate as great as 51 mm/year (the infiltration rate for the most permeable cover, the site soils cover, is 20 mm/year).

The nuclides selected and the source terms (Blacklaw, 1998) used for modeling the three closure dates are:

RADIONUCLIDE	YEAR 2000	YEAR 2056	YEAR 2215
Cl-36	4.79 Ci	4.91 Ci	5.23 Ci
I-129	5.66 Ci	6.01 Ci	7.02 Ci
Tc-99 [13]	61.9 Ci	67.1 Ci	81.8 Ci
U-235 [14]	7337 x 2 Ci	7337 x 2 Ci	7337 x 2 Ci
U-238	2227 x 10 Ci	2227 x 10 Ci	2227 x 10 Ci

The source terms for U-235 and U-238 have been multiplied by the factors of two and ten, respectively, because of errors made in the US Ecology site records for uranium disposal during the early years of operations. Based on WDOH‘s audit of US Ecology records, these multipliers are expected to more than adequately bound the actual U-235 and U-238 inventories. US Ecology and WDOH are currently in the process of correcting the uranium source term and recalculating the amount of uranium disposed.

The same source terms for U-235 and U-238 were used for all closure year alternatives; i.e., the years 2000, 2056, and 2215, for two reasons: (1) slightly differing source terms do not affect the peak concentration because U-235 and U-238 are solubility limited; and (2) increasing the source terms by factors as large as two and ten overwhelms any precision garnered by differentiating by closure dates. In addition to auditing US Ecology’s source term review work for uranium, WDOH is tracking the developments in the uranium solubility studies being conducted at Pacific Northwest National Laboratory. Should the solubility limit be increased, the modeling will have to be reviewed.

The uranium progeny were also modeled.

[13] Since the time the groundwater pathway modeling was performed, WDOH has modified its prediction of future WNP-2 reactor wastes to be disposed. Of these 5 nuclides, only Tc-99 source term was affected. The amount of curies of Tc-99 in WNP-2 waste increased from 0.0043 curies to 0.71curies. Thus the total for Tc-99 should be 62 (year 2000), 67.2 (year 2056), and 81.9 (year 2215) curies. The modeling was not repeated in order to make this source term change because the change is insignificant in light of other assumptions; especially since the source term for Tc-99 is based on extremely conservative waste manifest estimates.

[14] The source term for U-235 and for U-238 was under-reported in the 1960’s and 1970’s. During that time period, mass disposal quantities were not converted properly into curies. In order to compensate for this deficiency, U-235 source term was multiplied by a factor of two, U-238 by a factor of ten, to ensure that the source term modeled is greater than the quantity disposed. Since modeling was performed, audits by WDOH have confirmed that the source term for U-235 and U-238 is much less than the source term modeled (Ahmad, 2000).

4.0 Deterministic Modeling: UNSAT-H Computer Code

WDOH, with the assistance of Michael Fayer of Pacific Northwest National Laboratory, used the UNSAT-H Version 2.03 computer code (Fayer and Jones, 1990) to simulate the water flow through the site soils cover, the proposed cover, and a composite of the three enhanced covers and the thick homogenous cover. Only the upper layers of the proposed and alternative covers were modeled. The goal was to compare infiltration rates through the various covers and to provide net infiltration through the cover for GWSCREEN groundwater pathway modeling.

UNSAT-H Version 2.03 is a one-dimensional model that simulates the dynamic processes of infiltration, drainage, redistribution, surface evaporation, and the uptake of water from soil by plants. The mathematical bases of the model are Richard's equation for water flow, Fick's law for vapor diffusion, and Fourier's law for heat flow. UNSAT-H uses a fully implicit, finite difference method for solving the water and heat flow equations. Plant water uptake is introduced as a sink term at each node and is calculated as a function of root density, water content, and potential evapotranspiration. The simulated profile can be homogeneous or layered. The boundary conditions can be controlled as either constant (potential or temperature) or flux conditions to reflect actual conditions at a given site. The UNSAT-H computer code is described in Fayer and Jones, 1990.

4.1 Modifications for WDOH EIS Application

Three main modifications were made to Version 2.03 for this application:

a. Computer code changed from single to double precision.

This change allows mass balance errors to be reduced, but it increases the size of output files.

b. Time stepping algorithm altered.

The ability of the code to continue a problem with the time step size at the minimum value, even though the solution was unacceptable, was eliminated. Instead, the code is stopped if it tries to reduce the time step below the minimum acceptable value. Another change was to eliminate faulty logic in the time stepping algorithm that allowed the code to settle into an infinite loop.

c. Ritchie equation modified.

The Ritchie equation is used to partition potential evapotranspiration into potential transpiration and potential evaporation. It was recently discovered that the equation did not fit the original data as well as thought, particularly when leaf area index (LAI) values were low, as they typically are in desert communities. The original equation is:

$$PT = -0.21 + 0.7(LAI)^{0.5}$$

The revised equation is:

$$PT = 0.52(LAI)^{0.5}$$

The revised equation values are listed in Table 2, "Replacement of LAI and Ep/Eo Values."

4.2 Input Parameters and Boundary Conditions

The materials used in the cover layers are described below in Section 4.4, "Grain Size Information for Materials Modeled by UNSAT-H." The hydraulic characteristics of these materials used as parameter inputs are described in Table 3, "Hydraulic Parameters for Van Genuchten Equation."

UNSAT-H was run using a 30-year daily rainfall pattern for the Hanford site (1966 until 1995). These data are available from the Hanford meteorological station on the world wide web, at http://terrassa.pnl.gov:2080/HMS/". The precipitation and potential evapotranspiration data from this record was used to create the surface boundary condition. The bottom boundary condition was a steady-state condition found by iterative runs stating with the arbitrary condition of 1 bar (i.e., approximately 1000 cm of suction).

The LAI, which describes the amount of vegetation, and hence transpiration, was varied from 0.0 for the inactive summer and fall months, to 0.1 for the less active winter months (Link, 1998), to 0.25 for the active part of the growing season (Link et al, 1990).[15] An LAI of 0.25 is a conservative estimate; for comparison a sagebrush-bunchgrass community on the Hanford Reservation had an LAI of 0.40 (Link et al, 1990, pg. 169, Fig. 4, for year 1986). This leaf area index range should be verified with experimental vegetation plots at the site or by measuring actual site vegetation, with the soil characteristics matching the characteristics of the soil as modeled.

4.3 Modeling Limitations, Simplifications, and Assumptions of Cover System

Briefly, the limitations, simplifications, and assumptions made by applying the UNSAT-H code are:

- The same vegetative density and growth pattern was assumed for all covers and for all time periods.
- Only one-dimensional, downward flow is modeled.
- Only permeable cover layers are modeled; impermeable layers are not modeled.
- The cover layers modeled are modeled as designed, without degradation.

These limitations, simplifications, and assumptions and their implications are described in more detail below.

4.3.1 Vegetative Density and Growth Pattern

The same range of leaf area index (LAI)[16] was used for all cover designs, regardless of the composition of the top layers.[17] This simplifying assumption was used because the variation expected in vegetative density and growth pattern from cover to cover is minimal compared to (1) the seasonal variation of plant activity, and (2) the preciseness in knowledge for applying LAI values. Over time, the differences in the plant community between the various cover designs is likely to be minimal because the same processes will affect all covers. For instance, all covers will be affected by deposition of windblown material, natural progression of species, fire, and intrusion by non-native plants such as cheat grass and Russian thistle.[18, 19]

The LAI was varied from zero to 0.25 as described in Section 4.2 above.

[15] The less active period extends from day number 320 to day number 90 (day 1 is January 1; day 365 is December 31). The active period extends from day number 90 to day 150. The summer months, days 150 to 320, were assigned an LAI of zero.
[16] The LAI describes the amount of vegetation, and hence transpiration.
[17] Enhanced designs A, B, and C, and the thick homogenous cover design, have the same characteristics for the top few feet and so would exhibit the same plant growth.
[18] By using the same LAI, a baseline is available to compare between the designs of the alternative choices. The US Ecology proposed cover as designed with a gravel mulch top layer is expected to have a lower LAI than the enhanced cover designs, but a change to make the top layer similar to that of the enhanced designs is a minimal change and US Ecology is considering this change.
[19]WDOH also modeled the groundwater pathway with recharge rates of 51 mm/year and 70 mm/year. These rates correspond with the higher range of results from experimental studies of infiltration rates for disturbed sites. A cover with percolation rates corresponding to these infiltration rates, when modeled with GWSCREEN, do not meet the regulatory limits, just as a cover with an infiltration rate of 20 mm/year does not meet the limits (see Thatcher, et al, 2000).

4.3.2 One-Dimensional, Downward Flow and Impermeable Layers Exclusion Assumptions

UNSAT-H, being a one-dimensional model, exhibits “ponding” above the impermeable or very low-permeability barriers placed below the capillary break layer (drainage layer) in the proposed cover and in the enhanced design covers. In reality, the ”ponded” water is expected to travel horizontally within the capillary break layer and out the side of the cover, as long as the capillary break layer remains unclogged and continuous. However, this drainage to the side cannot be modeled with the one-dimensional UNSAT-H code. Therefore, UNSAT-H was used to model only the upper layers and not the low-permeability or impermeable layers. This simplification has the effect of lumping the three enhanced design covers and the thick silt homogenous cover alternative into one for UNSAT-H infiltration predictions. This simplification also means that no credit is taken for any capability of the lower layers of either the proposed cover or the enhanced design covers to intercept water and drain it out the side of the cover. Instead, these lower layers can be viewed as a “backup system” for these four cover alternatives, that was not included in the groundwater pathway modeling.

Therefore, when the different cover designs are evaluated and ranked, judgment must be used to factor in the importance and abilities of these lower layers of the designs and to rank the three enhanced covers against each other, against the thick silt homogenous cover (which lacks this “backup”), and against the proposed cover (which does have the “backup”). Due to the limitations in modeling, the results of modeling need to be balanced with other methods and standards of evaluating the various covers.

4.3.3 Covers Modeled as Designed

UNSAT-H was used to model the infiltration of the various cover alternatives “as designed.” UNSAT-H was not used to simulate such possible conditions as settlement, cracking, degradation of cover materials, clogging of gravel drain layers, burrowing by animals, destruction of vegetation by fire or disease, natural progression of vegetation, intrusion of deep rooted plants such as sage brush and Russian thistle, accumulation of windblown material onsite, or erosion due to wind. In addition to modeling results, the effects of these types of conditions and their relative importance to each of the alternative covers must be weighed in the overall evaluation and ranking of the alternative covers.

4.4 Grain Size Information for Materials Modeled by UNSAT-H

Table 4 summarizes the materials that were modeled for the three UNSAT-H cover designs (the US Ecology-proposed closure cap, the WDOH site soils cover, and a composite of the WDOH-enhanced covers), and lists the sources of information used to estimate parameters for these materials.[20] The sources of information are also briefly described below for the cover materials.

4.4.1 Silt Loam Material

McGee Ranch silt loam (from the McGee Ranch site, located to the northwest of the Yakima Barricade) is the source for the hydraulic parameters for the silt loam used in the UNSAT-H modeling. Those hydraulic parameters required for UNSAT-H modeling are reported in Fayer et al, 1992, an analysis of cover designs for the Hanford site.

4.4.2 Site Sand Material

Parameters for the site sand material came from hydraulic properties from onsite borehole samples. These borehole samples are described in the US Ecology Closure Plan (USE, 1996). Three of these samples (MW5[21], 50 ft.; MW8, 14.5 ft.; and MW10, 45 ft.) came from depths that might comprise a spoils pile (i.e., site sand). The US Ecology 1996 Closure Plan provides saturated hydraulic conductivity values for these samples. Khaleel and Freeman, 1995, provides the remaining UNSAT-H model parameters sampled from onsite wells.

4.4.3 Gravel Correction

The bulk hydraulic properties of the materials mixed with pea gravel were determined using a method proposed by Bouwer and Rice, 1983. The method involves calculating the bulk hydraulic properties of the mix from the hydraulic properties of the matrix (e.g., sand; silt loam) fraction alone and the volume fraction of the gravel.

[20] These materials are the sources for the hydraulic parameters and not materials that have been acquired for cover construction. Materials actually selected will have to be tested to meet design requirements.
[21] MW = monitoring well

4.5 UNSAT-H Results

Table 5, second column, lists the results of infiltration modeling using the UNSAT-H code. For cover designs with capillary breaks over low-permeability barrier layers (all cover alternatives except the thick homogenous cover and the site soils cover), the modeling was done for only those layers above the capillary breaks. The proposed cover alternative and the filled-site alternative are the same from the perspective of infiltration modeling, with the same four layers modeled. For the thick homogenous cover and three enhanced covers, a different set of four layers was modeled. The thick homogenous cover and three enhanced covers are similar above the capillary break and therefore were modeled as the same. Two layers were modeled for the site soils cover.

The UNSAT-H modeling results for all alternative covers are similar to infiltration rates predicted in other ways. The proposed cover (and filled site alternative) infiltration rate of 2.07 mm/year compares well with US Ecology's HELP code modeling, which predicts infiltration rates varying from 1.3 mm/year to 3.0 mm/year (USE, 1996). The site soils cover infiltration rate of 19.9 mm/year and the enhanced covers and thick homogenous cover infiltration rates of essentially zero[22] compares well with field lysimeter tests at Hanford (Fayer and Walters, 1995) (Gee et al, 1993) and with monitoring results of the Prototype Barrier, an instrumented test cover built in the 200 Area (DOE, 1999). In fact, the silt loam of the Prototype Barrier, over the four years during which the hydrologic performance has been measured, has shown drainage of only a fraction of 0.5 mm/yr. [23]

For GWSCREEN deterministic modeling, the infiltration rates for the proposed cover (and filled site alternative) and for the site soils cover were rounded to 2 mm/year and 20 mm/year. Also, for GWSCREEN modeling, the infiltration rates for the thick silt homogenous cover and for the three enhanced covers were increased to 0.5 mm/year. US DOE also used 0.5 mm/year as the infiltration rate for the Environmental Restoration Disposal Facility (ERDF) cover (US DOE, 1994). There is no reason to run GWSCREEN with an infiltration rate of zero; all doses would be zero. Table 5 presents the infiltration rates predicted by UNSAT-H, the comparable rate used in GWSCREEN deterministic modeling, and the number of layers modeled by UNSAT-H.

[22] UNSAT-H calculated the infiltration rate for the enhanced and thick silt homogenous cover designs as "less than 0.001 mm/year," which is essentially zero.

[23] The largest drainage which was measured was 0.07 mm/yr with an above normal level of natural precipitation and 0.02 mm/yr when 3-times the normal precipitation was applied. These amounts can be attributed in part or whole to condensation in the collection system (USDOE, 1999, pg 3-24).

5.0 Deterministic Modeling: GWSCREEN Computer Code Estimates of Groundwater Concentration and Travel Time

GWSCREEN, Version 2.5 (Rood, 1998), is a semi-analytical model which models contaminant leaching from the waste trench, and advective and dispersive transport in the unsaturated zone and aquifer. Doses may be calculated by GWSCREEN at a downgradient receptor well by inputting a water ingestion rate and dose conversion factor for the radionculides modeled; or as done in this application, groundwater concentrations at the well may be used for dose calculations outside the code. Normally, when using one of the built-in source models available in GWSCREEN, a steady-state infiltration from the waste trench to the aquifer is assumed. For this application, adjustments were made to allow for different water fluxes in the waste trench and vadose zone. These adjustments are described in Attachment 1, *Further Evaluation of Groundwater Concentrations for Different Covers at the US Ecology Low-Level Waste Disposal Site, Hanford Washington, Using GWSCREEN 2.5 and Minimizing the Cover's Effect at Depth.*

GWSCREEN was selected as the computer model for this dose assessment because it is an easy code to set up and run; it has the appropriate level of complexity for the amount of site hydrogeologic information known; and it is not a "black box", instead its workings are apparent and it can be easily matched to the conceptual model.

GWSCREEN 2.5 treats groundwater flow in the unsaturated and saturated zones as steady-state and unidirectional in a homogeneous and isotropic porous media. Water flow in the unsaturated zone is vertical (downward) and assumes unit-gradient conditions apply: that is, water movement is driven only by gravitational flow and a uniform pressure head with depth exists. Contaminant transport in the unsaturated zone is one-dimensional and three-dimensional in the aquifer.

Contaminant-specific properties include the linear sorption coefficient (Kd) and contaminant half-lives. Linear sorption, radioactive decay, and in-growth are included in the model. The model assumes radioactive decay products travel at the same rate as their parent, but adjustments for different sorption properties between the parent and progeny are made in the aquifer. These and other input parameters for GWSCREEN 2.5 deterministic modeling are given in the third column of Table 6.

GWSCREEN solves for maximum concentration in the groundwater for each nuclide modeled, time of maximum concentration, and peak dose.[24] WDOH used the near-term maximum concentrations and time as provided by GWSCREEN 2.5 as input into dose calculations for an offsite farmer and an onsite farmer, both of whom irrigate with contaminated water, work in the fields, and eat their own food products. This dose modeling is described in "*Radiological Assessment for the Commerical Low-Level Radioactive Waste Disposal Facility, Richland, Washington*" by Thatcher et al, 2000.

5.1 Leach Rate

An important simplifying assumption of the conceptual model is to ignore the amount of time for the various waste forms and waste packages to break down sufficiently to release the waste to the trench surroundings. This assumption is made due to the great variety of waste forms and packaging and limited amount of information as to how long the various waste forms and packages will remain intact. Therefore, as stated in the second assumption in Section 2, no credit is taken for the waste package or the waste form. In the GWSCREEN simulation, waste is assumed to be homogeneously mixed with the backfilled soil. The rate at which radionuclides leach from the waste trench is then a function of the water flux through the waste trench and the radionculide-specific sorptive properties for the backfilled soil. Although GWSCREEN allows for different sorptive properties in the waste trench, unsaturated zone, and aquifer, the sorption properties were assumed to be the same in all three media.

[24] GWSCREEN does predict dose, but only for drinking contaminated water; GWSCREEN does not include in its dose the consumption of food products contaminated by irrigating with contaminated water, and therefore dose results from GWSCREEN were not used.

5.2 Distribution Coefficients and Solubility Limits

Table 7, **"**Distribution Coefficients and Solubility Limits," lists the distribution coefficients used by WDOH in GWSCREEN**.** For each nuclide, the same distribution coefficients were used for the unsaturated and saturated zones, as well as for the backfill, as described in the leach rate section above. Distribution coefficients values are based on recent research at the U.S. DOE Hanford site and selected from Kincaid et al, 1998. Kincaid et al, 1998, lists a range of distribution coefficients, depending on the geochemical environment and the degree of conservativeness desired. WDOH used the Kd values given for the geochemical environment characterized by low organics, low salts, and near neutral Ph. WDOH selected the "conservative value" given by Kincaid et al, 1998, as opposed to the "best estimate value."

The solubility of a given constituent limits the amount of that constituent in the leachate. In order to mimic this limitation, a "solubility limit," when known, is applied in modeling. Should more of a certain radionuclide exist in the disposed waste than can be held in the moisture going through the waste and into the unsaturated zone, imposing a solubility limit allows the model to limit to a realistic level the amount of that radionuclide that travels into the unsaturated zone. Using solubility limits in a dose assessment can be the key to getting a realistic dose, as opposed to a very conservative (i.e., easily defendable) but larger and unrealistic dose. Unfortunately, solubilities of the inventory constituents, disposed along with some small amount of moisture from precipitation, are not well known. This is why, as seen in Table 7, all nuclides except uranium were assigned extremely high solubility limits by WDOH, such that there is essentially no solubility limit. For these nuclides, the only limit on the amount of a nuclide that can dissolve into the leachate and migrate through the unsaturated and saturated zones to the receptor is the inventory present.

WDOH did apply a solubility limit to uranium even though the correct value is hard to discern from the literature, because not having a limit is not realistic. Without a solubility limit, all the uranium is available for transport at once, which is not the case. Currently, research at PNL is being done to try to establish a solubility limit for uranium; preliminary results indicate that the limit may be as low as 1.0 mg/L (Serne et al, to be published in 2000), or even lower (Serne, 1999).

5.3 Infiltration Rates and Associated Moisture Content

Infiltration rates and moisture content values used in GWSCREEN are presented in Table 8, which also describes assumptions made and information sources. Note that the infiltration rates into and percolation through the cover and trenches differ from cover to cover, but for all covers, the percolation rate in the unsaturated zone is 5mm/year, equivalent to natural recharge.

With the exception of the site soils cover, the covers are expected to have an infiltration rate that is lower than the natural recharge rate. Therefore, there would be a reduction in the amount of moisture in the unsaturated zone below the cover, as compared to the amount of moisture in the unsaturated zone under the undisturbed area surrounding the site. At some depth, there will be an influx of moisture from the sides due to the moisture content gradient. The depth to which the reduction, or infiltration "shadow", is in effect cannot be solved by GWSCREEN. Therefore, it was assumed that the cover only limits moisture into the trenches, and not into the unsaturated zone. Thus, the infiltration rate and moisture content for the unsaturated zone under the trenches, was assumed to be the same as the unsaturated zone's natural infiltration rate and moisture content. Details are provided in the section, "Conceptual Model" in Attachment 1, *Further Evaluation of Groundwater Concentrations for Different Covers at the U.S. Ecology Low-Level Waste Disposal Site, Hanford Washington, Using GWSCREEN 2.5 and Minimizing the Cover's Effect at Depth*.

As described in Section 4 above, UNSAT-H predicted a percolation rate through the three enhanced cover designs and the thick homogenous cover of essentially zero. A zero percolation rate results in a maximum concentration of zero in the groundwater and a dose of zero. Because these "zero" answers do not provide any comparative information and because WDOH cannot be assured that the infiltration rate will stay zero over time, a higher value of 0.5 mm/year was used as the percolation value in GWSCREEN modeling. This non-zero value is the same as assumed by US DOE in their modeling of the Environmental Restoration Disposal Facility (ERDF) cover (US DOE, 1994).

The moisture contents listed in Table 8 (also listed in Table 6) for the trenches were estimated using moisture characteristic curves developed from a site-specific study of hydraulic properties of soils in Khaleel and Freeman (1995). Table 8 (and Table 6) also lists the infiltration rate and moisture content for natural recharge which was applied to the vadose zone below the trenches.

5.4 Progeny

The following nuclides were modeled with consideration to their decay chain (first progeny listed in parentheses): Am-241 (Np-237), Cm-242 (U-234), Cm-244 (Pu-240), Pu-238 (U-234), Pu-240 (U-236), and Pu-241 (Np-237). The inventory used for each is calculated, assuming secular equilibrium. Specifically, the activity of the parent ($\lambda_p N_p$) is equal to the activity of the daughter ($\lambda_d N_d$), as shown in the formula below:

$$\lambda_p N_p = \lambda_d N_d$$

where N = number of atoms and λ = 0.693/half-life = decay constant.

Progeny travel along with the parent; that is, they have the same travel times. None of the progeny contributed significantly to dose.

5.5 GWSCREEN Results

GWSCREEN 2.5 deterministic results are provided in Table 9. These concentrations are then used to calculate the dose for the offsite agricultural scenario. These calculations are described in "*Radiological Assessment for the Commercial Low-Level Radioactive Waste Disposal Facility, Richland, Washington*" by Thatcher et al, 2000. A concise description of the scenarios utilized is found in "*A Description of the Offsite Rural Resident and the Onsite Intruder Resident and Construction Workers*" (Thatcher, 1998).

6.0 Uncertainty Analysis: GWSCREEN

In addition to using GWSCREEN 2.5 to predict deterministic results for radionuclide concentrations in the groundwater, GWSCREEN 2.5 was also used to perform an uncertainty analysis of these concentrations. The uncertainty analysis was done for the site soils cover and for the enhanced covers.

The uncertainty analysis results, in the form of an Excel™ spreadsheet of 1,000 GWSCREEN time-versus-concentration realizations, was incorporated into the overall dose assessment uncertainty analysis as described in the uncertainty section of Thatcher et al, 2000. The time-versus-concentration realizations were for the five nuclides and for the uranium progeny.

The GWSCREEN uncertainty analysis was a "parametric uncertainty analysis;" that is, the uncertainty analysis considers only the model parameters. The analysis was not a "model uncertainty analysis;" that is, no attempt was made to quantify the uncertainty in the conceptual framework of the model. The analysis was performed by Dr. Arthur Rood of K-Spar, Inc. of Rigby, Idaho[25], and documented in Attachment 2, *Groundwater Pathway Uncertainty Analysis in Support of the Performance Assessment for the US Ecology Low-Level Radioactive Waste Facility.*

The stochastic analysis for the site soils cover assumed that the water flux through the unsaturated zone was the same as the water flux through the trench. This assumption differs from the one imposed on the deterministic analysis and the stochastic analysis for the enhanced covers where the water flux through the unsaturated zone is controlled by natural recharge around the cover. The site soils assumption is conservative because the site soils cover has a higher flux than does natural recharge. The purpose of the stochastic analysis of the site soils cover was to quantify the worst case doses that could possibly occur as a result of a catastrophic failure of the engineered barrier and assuming high infiltration conditions persist for over 10,000 years. It is important to understand the unlikelihood of this occurring because even if a catastrophic failure had occurred, over time soils would stratify, develop vegetation, and probably return to conditions that would mimic infiltration from undisturbed areas.

Attachment 2 provides scattergrams that display the range of peak concentration values at peak times as predicted by the uncertainty analysis for Cl-26, Tc-99, I-129, U-235, and U-238. The deterministic result is also displayed on each scattergram.

For a description of input parameters and distributions for the GWSCREEN 2.5 simulations, refer to Table 6. Table 6 provides the following:

- documents the source for the parameter input values and distributions that WDOH provided to Dr. Rood;
- identifies which parameter values and distributions were provided by Dr. Rood and documented in Attachments 1 and 2; and
- lists and compares parameter values for the deterministic analyses and the uncertainty analyses.

As described in Dunkelman et al, 1999, there is great uncertainty in the source terms for Tc-99, I-129, and both uranium nuclides. The source terms for Tc-99 and I-129 may be 10 or more times greater than that actually disposed. US Ecology is considering undertaking an elaborate procedure to reduce the source terms of Tc-99 and I-129 to more accurate levels. In any case, the source term for these nuclides is conservative. Conversely, the source terms for U-235 and for U-238 were under-reported because during record keeping in the 1960's and 1970's, mass disposal quantities were not converted properly into curies. In order to ensure that conservative values were used in modeling, WDOH multiplied by a factor of two the U-235 source term, and multiplied U-238 by a factor of ten. WDOH along with US

[25] K-Spar, Inc, 493 N 4154 E, Rigby, Idaho 83442.

Ecology is currently reviewing old records in order to provide a more accurate source term for uranium. The results to date are reported in Ahmad, 2000.

WDOH decided to not treat any of the nuclide source terms as part of the uncertainty analysis, so as to not cloud the results of the analysis. When the source term values are better known, the dose assessment analyses can incorporate the new information. In any case, a rough uncertainty analysis can be done by prorating the results to account for a variety of source terms.

7.0 Summary

Predicted radionuclide concentrations in groundwater from deterministic modeling are provided in Table 9 below. Predicted doses from the groundwater pathway and stochastic modeling results are provided in Thatcher et al, 2000.

8.0 Tables

TABLE 1

SOURCE TERM FOR INITIAL MODELING

ISOTOPE	HALF-LIFE (years)	ACTIVITY THROUGH 1996 (Curies) (1)	ACTIVITY THROUGH 2056 (Curies) (2)
Am-241	458	463.7	467.3
Cl-36	3.08E+05	4.8	4.9
H-3	12.3	785,141.8 (5)	852,505.9 (5)
I-129	1.70E+07	5.63	6.0
Nb-94	2.00E+04	.98	4.6
Ni-59	8.00E+04	187.6	1,352.2
Ni-63	92	36,944.2	230,163.6
Pu-238	86.4	10,588.9	10,597.3
Pu-239(3)	2.44E+04	6,450.7	6,481.2
Pu-242	3.79E5	239.2	239.3
Sr-90	27.7	44,424.4	50,413.1
Tc-99	2.12E+05	61.5	67.1
Th-232(4)	1.41E+10	209.7	436.7
U-235	7,04E+08	7,279.7	7,337.92
U-238	4.5E+09	2,222.71	2,227.95

(1) Current (1996) source term activities were taken from WDOH regulatory files.

(2) The future (2056) source term activities were calculated as described in Appendix 2 of the TER (Dunkelman et al, 1999).

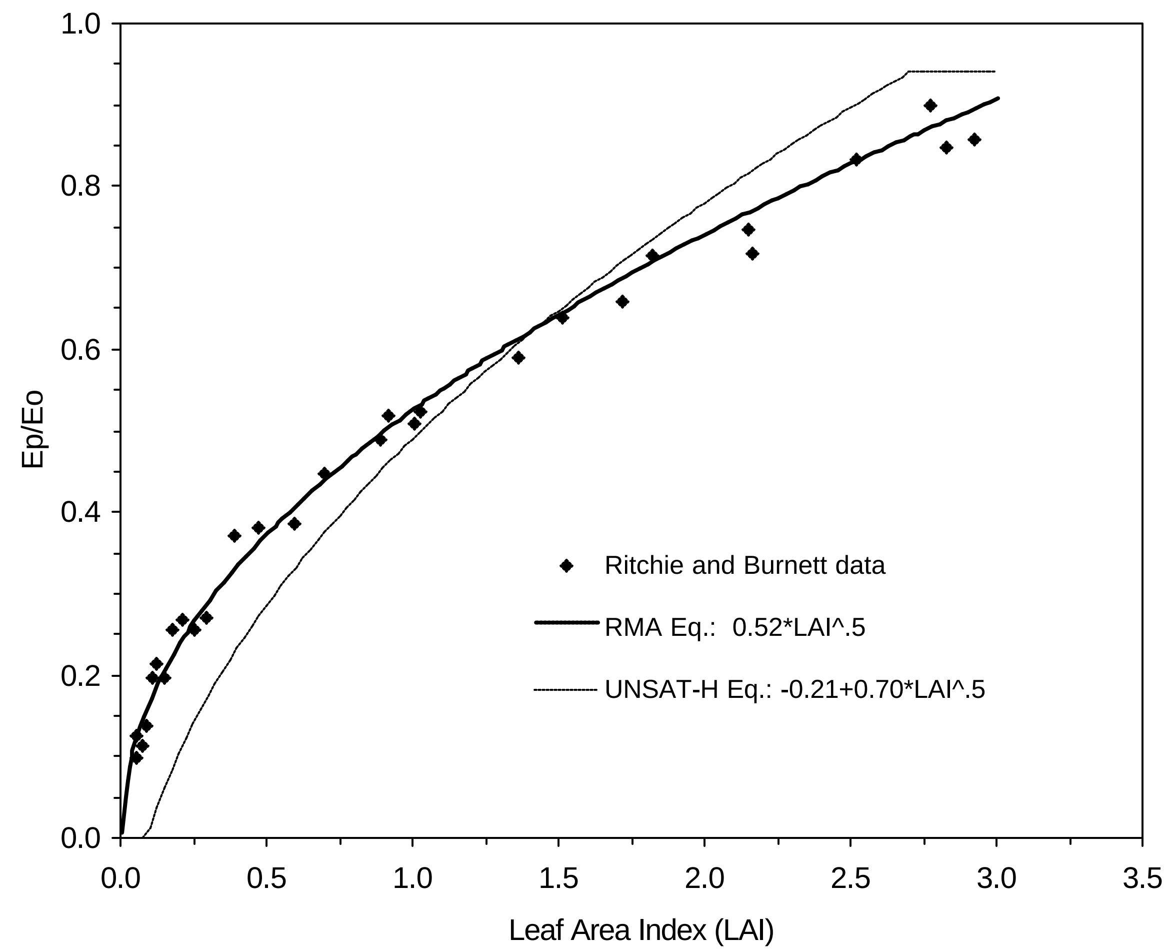
(3) Pu-239 includes Pu-239 and Pu-240 isotopes.

(4) Th-232 includes Th-230, Th-232, and Th-natural.

(5) When decay since burial is applied, the activity is greatly reduced. Described in Dunkelman, et al, 1999.

REPLACEMENT OF LAI AND Ep/Eo VALUES FROM RITCHIE/UNSAT-H EQUATION WITH RMA EQUATION VALUES

The graph below, Ep/Eo versus Leaf Area Index, plots Ritchie and Burnett (1971) data against the equation in the UNSAT-H model. It is not a good correlation. An improved correlation is given by the Rocky Mountain Arsenal (RMA) equation also plotted below. The RMA equation is provided by Mark Ankeny of Stan Stevens and Associates, Albuquerque, New Mexico (as yet unpublished).



KEY

RMA = Rocky Mountain Arsenal

Ep = potential transpiration

Eo = sum potential transpiration and potential evaporation

LAI = Leaf Area Index

Eq = equation

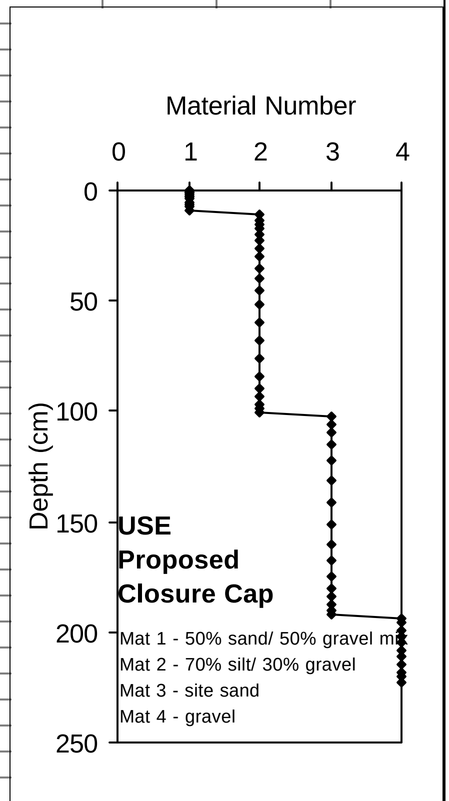
TABLE 2 - PAGE 2 OF 2

REPLACEMENT OF LAI AND Ep/Eo VALUES FROM RITCHIE/UNSAT-H EQUATION WITH RMA EQUATION VALUES

Digitized Values from Figure 10 of Ritchie and Burnett (1971)		Conversion of digitized values in columns 1 and 2 to LAI and Ep/Eo		Conversion of Rocky Mountain Arsenal Values to Ritchie Values Ep/Eo								
x (cm)	y (cm)	LAI	Ep/Eo	LAI	RMA eq.	Ritchie eq.	LAI	RMA eq.	Ritchie eq.	LAI	RMA eq.	Ritchie eq.
0.350	2.100	0.053	0.125	0.000	0.000	0.000	1.000	0.520	0.490	2.000	0.735	0.780
0.350	1.650	0.053	0.098	0.025	0.082	0.000	1.025	0.526	0.499	2.025	0.740	0.786
0.600	2.300	0.090	0.137	0.050	0.116	0.000	1.050	0.533	0.507	2.050	0.745	0.792
0.500	1.900	0.075	0.113	0.075	0.142	0.000	1.075	0.539	0.516	2.075	0.749	0.798
1.000	3.300	0.150	0.196	0.100	0.164	0.011	1.100	0.545	0.524	2.100	0.754	0.804
0.800	3.600	0.120	0.214	0.125	0.184	0.037	1.125	0.552	0.532	2.125	0.758	0.810
0.750	3.300	0.113	0.196	0.150	0.201	0.061	1.150	0.558	0.541	2.150	0.762	0.816
1.950	4.550	0.293	0.271	0.175	0.218	0.083	1.175	0.564	0.549	2.175	0.767	0.822
1.700	4.300	0.255	0.256	0.200	0.233	0.103	1.200	0.570	0.557	2.200	0.771	0.828
1.400	4.500	0.210	0.268	0.225	0.247	0.122	1.225	0.576	0.565	2.225	0.776	0.834
1.200	4.300	0.180	0.256	0.250	0.260	0.140	1.250	0.581	0.573	2.250	0.780	0.840
4.650	7.500	0.698	0.446	0.275	0.273	0.157	1.275	0.587	0.580	2.275	0.784	0.846
3.950	6.500	0.593	0.387	0.300	0.285	0.173	1.300	0.593	0.588	2.300	0.789	0.852
3.150	6.400	0.473	0.381	0.325	0.296	0.189	1.325	0.599	0.596	2.325	0.793	0.857
2.600	6.250	0.390	0.372	0.350	0.308	0.204	1.350	0.604	0.603	2.350	0.797	0.863
5.950	8.200	0.893	0.488	0.375	0.318	0.219	1.375	0.610	0.611	2.375	0.801	0.869
6.100	8.700	0.915	0.518	0.400	0.329	0.233	1.400	0.615	0.618	2.400	0.806	0.874
6.700	8.550	1.005	0.509	0.425	0.339	0.246	1.425	0.621	0.626	2.425	0.810	0.880
6.850	8.800	1.028	0.524	0.450	0.349	0.260	1.450	0.626	0.633	2.450	0.814	0.886
9.100	9.900	1.365	0.589	0.475	0.358	0.272	1.475	0.632	0.640	2.475	0.818	0.891
10.100	10.750	1.515	0.640	0.500	0.368	0.285	1.500	0.637	0.647	2.500	0.822	0.897
11.450	11.050	1.718	0.658	0.525	0.377	0.297	1.525	0.642	0.654	2.525	0.826	0.902
12.150	12.000	1.823	0.714	0.550	0.386	0.309	1.550	0.647	0.661	2.550	0.830	0.908
14.350	12.550	2.153	0.747	0.575	0.394	0.321	1.575	0.653	0.668	2.575	0.834	0.913
14.450	12.050	2.168	0.717	0.600	0.403	0.332	1.600	0.658	0.675	2.600	0.838	0.919
16.800	14.000	2.520	0.833	0.625	0.411	0.343	1.625	0.663	0.682	2.625	0.842	0.924
18.500	15.100	2.775	0.899	0.650	0.419	0.354	1.650	0.668	0.689	2.650	0.846	0.930
18.850	14.250	2.828	0.848	0.675	0.427	0.365	1.675	0.673	0.696	2.675	0.850	0.935
19.500	14.400	2.925	0.857	0.700	0.435	0.376	1.700	0.678	0.703	2.700	0.854	0.940
				0.725	0.443	0.386	1.725	0.683	0.709	2.725	0.858	0.940
				0.750	0.450	0.396	1.750	0.688	0.716	2.750	0.862	0.940
				0.775	0.458	0.406	1.775	0.693	0.723	2.775	0.866	0.940
				0.800	0.465	0.416	1.800	0.698	0.729	2.800	0.870	0.940
				0.825	0.472	0.426	1.825	0.702	0.736	2.825	0.874	0.940
				0.850	0.479	0.435	1.850	0.707	0.742	2.850	0.878	0.940
				0.875	0.486	0.445	1.875	0.712	0.749	2.875	0.882	0.940
				0.900	0.493	0.454	1.900	0.717	0.755	2.900	0.886	0.940
				0.925	0.500	0.463	1.925	0.721	0.761	2.925	0.889	0.940
				0.950	0.507	0.472	1.950	0.726	0.767	2.950	0.893	0.940
				0.975	0.513	0.481	1.975	0.731	0.774	2.975	0.897	0.940
										3.000	0.901	0.940

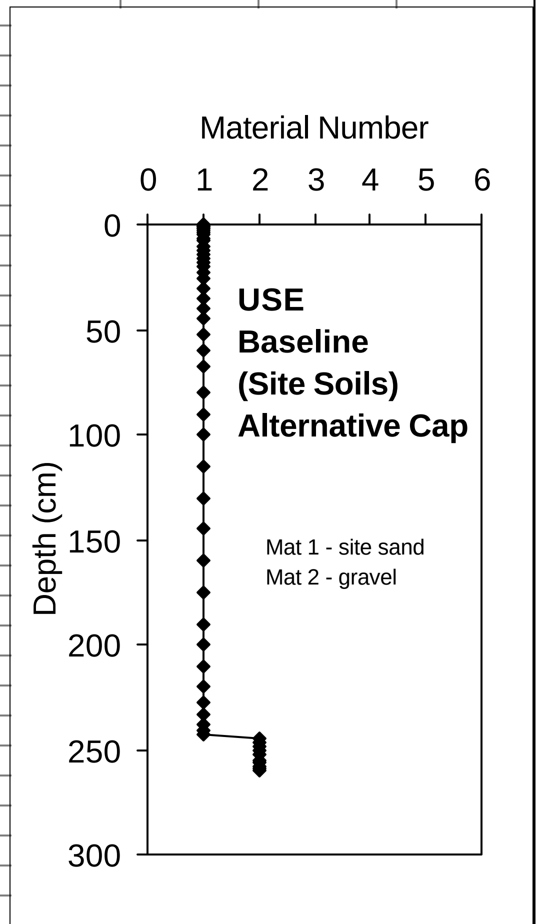
HYDRAULIC PARAMETERS FOR VAN GENUCHTEN EQUATION

	4	64, matn,npt		
Node N	Material No.	Node Z, cm	ZZ, cm	Change in ZZ < 50%?
1	1	0		
2	1	0.2	0.2	
3	1	0.4	0.2	ok
4	1	0.6	0.2	ok
5	1	0.8	0.2	ok
6	1	1	0.2	ok
7	1	1.3	0.3	ok
8	1	1.7	0.4	ok
9	1	2.3	0.6	ok
10	1	3	0.7	ok
11	1	4	1	ok
12	1	5	1	ok
13	1	6.3	1.3	ok
14	1	7.6	1.3	ok
15	1	9.16	1.56	ok
16	2	11.16	2	ok
17	2	13.16	2	ok
18	2	15.25	2.09	ok
19	2	17.5	2.25	ok
20	2	20	2.5	ok
21	2	23	3	ok
22	2	26	3	ok
23	2	30	4	ok
24	2	35	5	ok
25	2	40	5	ok
26	2	45	5	ok
27	2	52	7	ok
28	2	60	8	ok
29	2	68	8	ok
30	2	76	8	ok
31	2	84	8	ok
32	2	89.5	5.5	ok
33	2	93.5	4	ok
34	2	96.5	3	ok
35	2	98.6	2.1	ok
36	2	100.6	2	ok
37	3	102.6	2	ok
38	3	105.6	3	ok
39	3	110	4.4	ok
40	3	115	5	ok
41	3	122	7	ok
42	3	131	9	ok
43	3	141	10	ok
44	3	151	10	ok
45	3	160	9	ok
46	3	168	8	ok
47	3	175	7	ok
48	3	180	5	ok
49	3	184	4	ok
50	3	187.5	3.5	ok
51	3	190.04	2.54	ok
52	3	192.04	2	ok
53	4	194.04	2	ok
54	4	196.04	2	ok
55	4	199	2.96	ok
56	4	202	3	ok
57	4	205	3	ok
58	4	208	3	ok
59	4	211	3	ok
60	4	215	4	ok
61	4	218.3	3.3	ok
62	4	220.52	2.22	ok
63	4	222.52	2	ok
64	4	223.52	1	-100



HYDRAULIC PARAMETERS FOR VAN GENUCHTEN EQUATION

	2 56 matn,npt			
Node N	Material No.	Node Z, cm	ZZ, cm	Change in ZZ < 50%?
1	1	0		
2	1	0.2	0.2	
3	1	0.4	0.2	ok
4	1	0.6	0.2	ok
5	1	0.8	0.2	ok
6	1	1	0.2	ok
7	1	1.3	0.3	ok
8	1	1.7	0.4	ok
9	1	2.3	0.6	ok
10	1	3	0.7	ok
11	1	4	1	ok
12	1	5	1	ok
13	1	6.5	1.5	ok
14	1	8	1.5	ok
15	1	10	2	ok
16	1	12	2	ok
17	1	14	2	ok
18	1	16	2	ok
19	1	18	2	ok
20	1	20	2	ok
21	1	23	3	ok
22	1	26	3	ok
23	1	30	4	ok
24	1	35	5	ok
25	1	40	5	ok
26	1	45	5	ok
27	1	52	7	ok
28	1	60	8	ok
29	1	68	8	ok
30	1	80	12	ok
31	1	90	10	ok
32	1	100	10	ok
33	1	115	15	ok
34	1	130	15	ok
35	1	145	15	ok
36	1	160	15	ok
37	1	175	15	ok
38	1	190	15	ok
39	1	200	10	ok
40	1	210	10	ok
41	1	220	10	ok
42	1	227.5	7.5	ok
43	1	233.75	6.25	ok
44	1	238.0	4.25	ok
45	1	240.84	2.84	ok
46	1	242.84	2	ok
47	2	244.84	2	ok
48	2	246.84	2	ok
49	2	248.84	2	ok
50	2	250.84	2	ok
51	2	252.84	2	ok
52	2	254.84	2	ok
53	2	256.5	1.66	ok
54	2	257.8	1.3	ok
55	2	258.8	1	ok
56	2	259.8	1	ok



	4 72 matn,npt			
Node I	Material No.	Node Z, cm	ZZ, cm	Change in ZZ < 50%?
1	1	0		
2	1	0.2	0.2	
3	1	0.4	0.2	ok
4	1	0.6	0.2	ok
5	1	0.8	0.2	ok
6	1	1	0.2	ok
7	1	1.3	0.3	ok
8	1	1.7	0.4	ok
9	1	2.3	0.6	ok
10	1	3	0.7	ok
11	1	4	1	ok
12	1	5	1	ok
13	1	6.5	1.5	ok
14	1	8	1.5	ok
15	1	10	2	ok
16	1	13	3	ok
17	1	17	4	ok
18	1	22	5	ok
19	1	28	6	ok
20	1	36	8	ok
21	1	46	10	ok
22	1	55	9	ok
23	1	61	6	ok
24	1	65	4	ok
25	1	68	3	ok
26	1	71	3	ok
27	1	73.2	2.2	ok
28	1	75.2	2	ok
29	2	77.2	2	ok
30	2	79.2	2	ok
31	2	82	2.8	ok
32	2	86	4	ok
33	2	92	6	ok
34	2	100	8	ok
35	2	110	10	ok
36	2	120	10	ok
37	2	130	10	ok
38	2	137	7	ok
39	2	142.5	5.5	ok
40	2	146.5	4	ok
41	2	149.4	2.9	ok
42	2	151.4	2	ok
43	3	153.4	2	ok
44	3	155.4	2	ok
45	3	158.2	2.8	ok
46	3	162	3.8	ok
47	3	167	5	ok
48	3	174	7	ok
49	3	184.0	10	ok
50	3	197	13	ok
51	3	212	15	ok
52	3	230	18	ok
53	3	250	20	ok
54	3	265	15	ok
55	3	275	10	ok
56	3	285	10	ok
57	3	294	9	ok
58	3	300	6	ok
59	3	304	4	ok
60	3	307	3	ok
61	3	309.42	2.42	ok
62	3	311.42	2	ok
63	4	313.42	2	ok
64	4	315.42	2	ok
65	4	317.42	2	ok
66	4	319.42	2	ok
67	4	321.42	2	ok
68	4	323.2	1.78	ok
69	4	324.66	1.46	ok
70	4	325.66	1	ok
71	4	326.66	1	ok
72	4	327.66	1	ok

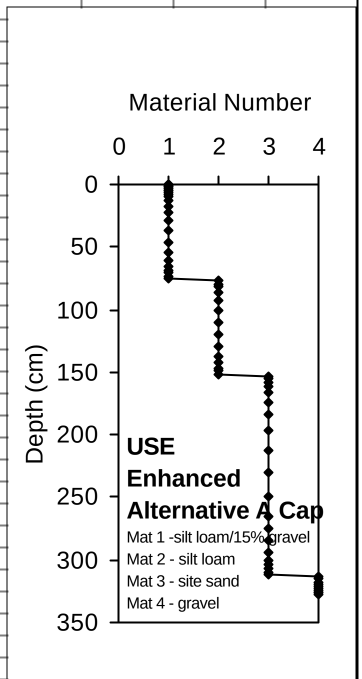


TABLE 4

MATERIALS AND THEIR THICKNESSES AS USED IN UNSAT-H COVER RECHARGE EVALUATIONS

Materials (from top of cover down)	**Thicknesses (in.) of Cover Layers**			**Data Sources**
	USE Proposed Cover	Site Soils	Enhanced Cover Designs	
50% site sand mixed with 50% gravel	4			Same as for site sand; with correction for gravel content
85% silt loam mixed with 15% gravel			30	Same as for site sand; with correction for gravel content
70% silt loam mixed with 30% gravel	36			Same as for site sand; with correction for gravel content
Silt loam			30	Fayer et al, 1992
Site sand	36	96	63	US Ecology Site Closure Plan,1996; Khaleel and Freeman, 1995 (USE site well information)
Gravel	12	6	6	Fayer et al, 1992,
Number of layers	4	2	4	

TABLE 5

COMPARISON OF UNSAT-H CODE PREDICTED INFILTRATION RATES WITH INFILTRATION RATES USED IN GWSCREEN MODELING

Cover Alternative Modeled	UNSAT-H Predicted Infiltration Rates, Top Layers	**Infiltration Rates Used in GWSCREEN Modeling**	**Number of Layers Modeled**
Proposed Cover	2.07 mm/year	2 mm/year	4
Thick Silt Homogenous Cover(1)	less than .001 mm/year (2)	0.5 mm/year	4
Site Soils Cover	19.9 mm/year	20 mm/year	2
Filled Site Alternative	2.07 mm/year	2 mm/year	4
Enhanced Asphalt Cover	less than .001 mm/year (2)	0.5 mm/year	4
Enhanced Synthetic Cover	less than .001 mm/year (2)	0.5 mm/year	4
Enhanced Bentonite Cover	less than .001 mm/year (2)	0.5 mm/year	4

(1) The same modeling results as the enhanced cover designs, but in reality would probably over time have a higher infiltration rate than the enhanced cover designs because the thick homogenous cover does not have redundant layering.

(2) UNSAT-H modeling results are reported as “less than .001 mm/year,” which is essentially zero. In order to be conservative, 0.5 mm/year (0.0005 m/year), is the value actually used in GWSCREEN computer code modeling. There is no reason to run GWSCREEN with an infiltration rate of zero; all doses would be zero.

TABLE 6

INPUT PARAMETERS AND DISTRIBUTIONS FOR THE GWSCREEN SIMULATIONS

Parameter Name (GWSCREEN Variable)		**Deterministic Modeling Value: GWSCREEN Version 2.4a**	**Deterministic Reference & Comment**	**Description**	**Distribution Assigned for Uncertainty Analysis: GWSCREEN version 2.5 for Site Soils Cover**	**Uncertainty Analysis Reference & Comment**
Length (AL)		518 m	Site map	Length of source parallel to groundwater flow	Fixed value, used same value as deterministic model	
Width (WA)		382 m	Site map	Width of source perpendicular to ground water flow	Fixed value, used same value as deterministic model	
Distance to receptor (XD)		275 m	Site map, at fenceline	Measured from center of source. 16 feet from edge of trench (XD - AL/2)	Fixed value, used same value as deterministic model	
Percolation rate (PERC) Also in table form, see note "a" below.		Site soils cover: 20 mm/yr Proposed cover: 2 mm/yr Enhanced & thick homogenous covers: 0.5 mm/yr Vadose zone: 5 mm/yr	Covers: UNSAT-H modeling; Vadose zone: literature search, including Wood, 1996; Kincaid, 1998.		Site soils cover: Triangular distribution, minimum = 15 mm y^{-1}, most likely = 20 mm y^{-1}, maximum = 50 mm y^{-1}. Enhanced cover: Weighted between 0.5 to 3 mm y^{-1}, minimum = 0.01 mm y^{-1} most likely = 0.5 mm y^{-1} maximum = 10 mm y^{-1}	Attachment 2 and Dunkelman, 2000.
Moisture content, source, & unsaturated zone (THETAS & THETAU). Also see note "a" below.	**	In trench under: Site soils cover: 5.1% Proposed cover: 3.7% Enhanced & thick homogenous covers: 3.4%	Khaleel & Freeman, 1995		In trench under: Site soils cover: For percolation rates between 15 and 50 mm/y, varied from 5% to 5.6 % Enhanced cover, varied from 3.5 to 4.8 % (3.6% for mean)	Calculated from Van Genuchten parameters from facility wells (attachment 2, figure 2) and from (Khaleel & Freeman, 1995)

Parameter Name (GWSCREEN Variable)		Deterministic Modeling Value: GWSCREEN Version 2.4a	Deterministic Reference & Comment	Description	Distribution Assigned for Uncertainty Analysis: GWSCREEN version 2.5 for Site Soils Cover	Uncertainty Analysis Reference & Comment
		In unsaturated zone: 4.6%				
Thickness (THICKS)		10.6 m	USE, 1996 D 2-12	Thickness of source	Fixed value, used same value as deterministic model	
Bulk density of source (RHOS)		1.26 g cm^{-3}	USE, 1996 5-27	Density of trench content	Triangular distribution, minimum=1.008, most likely=1.26, maximum=1.512 g cm^{-3}	Assumed +/_ variance of 20%
Depth to aquifer (DEPTH)		82.3 m	Site well logs. Excluded thickness of waste. Conservative as depth increasing with suspension of Hanford operations.		Fixed value, used same value as deterministic model	
Bulk density of unsaturated zone (RHOU)		1.6 g cm^{-3}	USE, 1996 D 4, D 5-11; Holdren et al, 1995		Triangular distribution, minimum=1.52, most likely=1.6, maximum=1.98 g cm^{-3}	From data for 46 ft to 240 ft Fayer, phone call
Dispersivity in unsaturated zone (AXU)	*	0.0 m	Dispersivity in unsaturated zone not included in deterministic model, GWSREEN version 2.4a		Truncated normal distribution, mean =4.0 m, standard deviation=2.0 m, minimum=0.0 m, maximum=6.0 m	Xu and Eckstein (1995) as reported in Attachment 2 and Rood (1998)
Longitudinal dispersivity, aquifer (AX)		27.5 m	Assumed 1/10th of distance to receptor. Data available for Ringold, 200E – longitudinal 50 m (Holdren, et al, 1995)		Triangular distribution, minimum=13.75 m, most likely=27.5 m, maximum=41.25 m	Assumed +/_ variance of 50%
Transverse dispersivity, aquifer (AY)		5.0 m	Assumed approximately 1/5th of longitudinal dispersivity. Data available for Ringold, 200E - transverse 10 m (Holdren et al, 1995)		Triangular distribution, minimum=2.5 m, most likely=5.0 m, maximum=7.5 m	Assumed +/_ variance of 50%
Aquifer thickness (THICK; version 2.4a) = Well screen thickness (B; version 2.5))		15 m	USE, 1996 2.7.2.2.1	Screen depth	Fixed value, used same value as deterministic model	Water table dropping. Aquifer thickness at X time

Parameter Name (GWSCREEN Variable)		Deterministic Modeling Value: GWSCREEN Version 2.4a	Deterministic Reference & Comment	Description	Distribution Assigned for Uncertainty Analysis: GWSCREEN version 2.5 for Site Soils Cover	Uncertainty Analysis Reference & Comment
Darcy velocity in aquifer (U)		32.9 m y^{-1} NOT USED IN DETERMINISTIC MODELING	Average linear velocity, used in deterministic model (not Darcy velocity)		Truncated lognormal distribution, geometric mean=32.9 m y^{-1} (see note "b" below), geometric standard deviation=2.33, minimum=3.0 m y^{-1}, maximum=250 m y^{-1}	Based on K and Hydraulic Gradient, Porosity fixed at 10% (Thorne, 1999; Connelly et al, 1992)
Average pore (linear) velocity (VX)		333 m y-1		Saturated pore velocity	NOT USED IN UNCERTAINTY ANALYSIS	
Saturated Hydraulic Conductivity (K)		NOT USED			USED TO CALCULATE DARCY VELOCITY v = K * gradient / effective porosity	2-200m/d, (30 m/d best estimate). Well 699-33-56: K = 50 m/d SE of site; Well 699-36-61B: K =8 m/d NW of site. (Connelly et al, 1992)
Hydraulic Gradient of Saturated Zone		NOT USED			USED TO CALCULATE DARCY VELOCITY v = K * gradient / effective porosity	0.002 to 0.004 without artificial recharge (Thorne, 1999). For the year 2350, 0.003 (Cole et al, 1998)
Porosity of aquifer (PHI)		0.1	USE, 1996 2-30		Triangular distribution, minimum=0.97, most likely=0.1, maximum=0.103	Cole et al, 1998, and Cole phone call
Bulk density of aquifer (RHOA)		1.6 g cm^{-3}	Holdren et al, 1995. Middle Ringold, sandy gravel		Triangular distribution, mini-mum=1.52, most likely=1.6, maximum=1.98 g cm^{-3}	Assumed +/_ variance of 20%
Distribution coefficient, Cl (KDS)	*	0.0 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Picked conservative value		Truncated normal distribu-tion, mean = 0.01 mL g^{-1}, standard deviation = 026 mL g^{-1}, minimum = 0.0 mL g^{-1}, maximum = 0.6 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, I (KDS)		0.3 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 0.3 mL g^{-1}, geometric standard deviation = 2.33, minimum = 0.2 mL g^{-1}, maximum = 15 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, Tc (KDS)	*	0.0 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated normal distribution, mean = 0.01 mL g^{-1}, standard deviation = 0.26 mL g^{-1}, minimum = 0.0 mL g^{-1}, maximum = 0.6 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2 .

Parameter Name (GWSCREEN Variable)		Deterministic Modeling Value: GWSCREEN Version 2.4a	Deterministic Reference & Comment	Description	Distribution Assigned for Uncertainty Analysis: GWSCREEN version 2.5 for Site Soils Cover	Uncertainty Analysis Reference & Comment
Distribution coefficient, U (KDS)	*	0.6 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 3.0 mL g^{-1}, geometric standard deviation = 3.65, minimum = 0.1 mL g^{-1}, maximum = 79 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, Th (KDA)	*	40 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 600 mL g^{-1}, geometric standard deviation = 2.1, minimum = 40 mL g^{-1}, maximum = 2000 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, Ra (KDA)	*	8 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 20 mL g^{-1}, geometric standard deviation = 2.0, minimum = 5 mL g^{-1}, maximum = 173 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, Pb (KDA)	*	2000 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Uniform distribution; minimum 2000 mL g^{-1}, maximum 6000 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Distribution coefficient, Pa (KDA)		0.6 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 0.6 mL g^{-1}, geometric standard deviation = 3.65, minimum = 0.01 mL g^{-1}, maximum = 79 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2 .
Distribution coefficient, Ac (KDA)		100 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10		Truncated lognormal distribution, geometric mean = 100 mL g^{-1}, geometric standard deviation = 1.9, minimum = 60 mL g^{-1}, maximum = 1330 mL g^{-1}	Kincaid et al, 1998 (Assumed low organic/low salt/near neutral pH), table E.10. Used range as given, best value used as mean. Shape of distribution described in Attachment 2.
Solubility limit, U (SL)	*	1 mg L^{-1}	Hanford site information	See TER Appendix 5 (Dunkelman et al, 1999)	Triangular distribution minimum = 1.0, most likely = 25, maximum = 50.	Attachment 2.

a. For deterministic modeling, moisture contents in trench as related to percolation:

Cover	Percolation Rate	Moisture Content
Enhanced/Thick Homogenous	0.0005 m/year	3.4%
Proposed	0.002 m/year	3.7%
Site Soils	0.02 m/year	5.1%

For stochastic modeling, moisture contents in trench as related to percolation:

Cover	Percolation Range	Moisture Content Range
Enhanced/Thick Homogenous	0.0005 m/year	3.5-4.8% (3.6% for mean value)
Site Soils	0.02 m/year	5.0-5.6%

b. For all covers, percolation and moisture content in vadose zone below trenches is the same as surrounding the site: 5mm/yr, 4.6%.
There are some small inconsistencies between these values and those used in Monte Carlo sampling which are not expected to change results appreciably. Monte Carlo sampling was performed for the Darcy Velocity from a distribution with a geometric mean of 32.0 m y^{-1} instead of 32.9 m y^{-1}

* Deterministic value does not equal mean or most likely value of uncertainty analysis, but does fall within range of uncertainty analysis values.

****** Deterministic value does not fall within range of uncertainty analysis values.

RADIONUCLIDE INVENTORIES USED IN UNCERTAINTY ANALYSIS

Radionuclide	Source Term Inventory (Ci)
Cl-36	4.907
I-129	6.012
Tc-99	67.1
U-235	14,680
U-238	22,280

TABLE 7

DISTRIBUTION COEFFICIENTS AND SOLUBILITY LIMITS

NUCLIDE (2)	DISTRIBUTION COEFFICIENT (Kd) (mL/g) (1)	SOLUBILITY LIMIT
Am-241 (Np-237)	10	1,000,000
Cl-36	0	1,000,000
H-3	0	1,000,000
I-129	0.3	1,000,000
Nb-94	20	1,000,000
Ni-59	50	1,000,000
Ni-63	50	1,000,000
Pu-238 (U-234)	0.6	1,000,000
Pu-239	80	1,000,000
Pu-242	80	1,000,000
Sr-90	8	1,000,000
Tc-99	0	1,000,000
Th-232	40	1,000,000
U-235	0.6	1 (3)
U-238	0.6	1

(1) WDOH distribution coefficient source: Kincaid et al, 1998.
(2) WDOH modeled the nuclide as if it was the progeny listed in parentheses
(3) WDOH uranium solubility limit source: Serne et al, 1999; and Finch, 1997.

TABLE 8

INFILTRATION RATES AND MOISTURE CONTENTS FOR THE ALTERNATIVE COVERS

Cover	Infiltration/ Percolation Rate	Moisture Content In Trench	Assumptions and References for Infiltration Rate/Moisture Content
Enhanced Covers and Thick Homogenous Cover	0.0005 m/year (0.5 mm/year) (0.02 in/year)	3.4%	U.S. DOE modeling assumption for the Environmental Restoration Disposal Facility (ERDF) cover (US DOE, 1994). Conservative increase from UNSAT-H prediction of <0.000001 m/year, which is essentially zero recharge. // Percent from Khaleel & Freeman, 1995.
Proposed Cover (and Filled Site Alternative)	0.002 m/year (2 mm/year) (0.08 in/year)	3.7%	Rate, as predicted by UNSAT-H code, is for the top four layers of the proposed cover; that is, the layers above the low-permeability barrier layer. Re-vegetated as completely as the enhanced cover designs. // Percent from Khaleel & Freeman, 1995.
Site Soils Cover	0.02 m/year (20 mm/year) (0.8 in/year)	5.1%	Rate, as predicted by UNSAT-H code, for waste covered with site soil (backfill and surcharge) instead of an engineered cover; re-vegetated as completely as enhanced cover designs. This infiltration rate provides a rough idea of concentrations, time of travel, and dose if there were no cover, or if the cover failed dramatically. // Percentage from figure 2, Attachment 2.
Below the Cover	**Infiltration/ Percolation Rate**	**Moisture Content Below Trench**	**Assumptions and References for Infiltration Rate/Moisture Content**
Vadose Zone below trenches/ Natural Recharge	0.005 m/year (5 mm/year) (0.2 in/year)	4.6%	Rate as measured at US DOE facility, 200 Area for non-disturbed areas. (Wood, 1996; Kincaid, 1998) // Percentage from figure 2, Attachment 2.

TABLE 9

GWSCREEN PREDICTED MAXIMUM GROUNDWATER CONCENTRATIONS in PCi/L
Within 10,000 years
[TRAVEL TIMES IN YEARS]

ALTERNATIVE and CLOSURE DATE	INFILTRATION RATE	Cl-36	I-129	Tc-99	U-235	U-238
Calculated by GWSCREEN:						
Enhanced Cover Designs/Thick Homogenous Design-2056	0.5 (mm/year)	20 [1,000]	1.9 [10,000] *	270 [1,000]	0.057 [10,000] **	0.0089 [10,000]
Proposed Cover-2056	2 (mm/year)	36 [900]	3.9 [9,750]	490 [900]	0.23 [10,000] **	0.036 [10,000]
Site Soils-2056	20 (mm/year)	46 [700]	4.9 [8,000]	630 [700]	2.3 [10,000] **	0.36 [10,000]
Calculated by prorating results above by ratio of source term activities : (1)						
Enhanced Bentonite Cover -2000	0.5 (mm/year)	19 [1,000]	1.8 [10,000]*	250 [1,000]	0.057 [10,000] **	0.0089 [10,000]
Filled Site Alternative -2215	2 (mm/year)	38 [900]	4.5 [9,750]	590 [900]	0.23 [10,000] **	0.036 [10,000]
Site Soils-2000	20 mm/year)	45 [700]	4.6 [8,000]	580 [700]	2.3 [10,000] **	0.36 [10,000]

* Maximum is predicted to occur at around 12,000 years** Maximum is predicted to occur much later than 10 000 years.

SOURCE TERMS USED FOR ABOVE RESULTS (Ci)

RADIONUCLIDE	Year 2000	Year 2056	Year 2215
Cl-36 (2)	4.79	4.91	5.23
I-129 (2)	5.66	6.01	7.02
Tc-99 (2)	61.9	67.1	81.8
	All Years		
U-235	14,680		
U-238	22,280		

(1) Because the maximum groundwater concentrations for Cl-36, Tc-99, and I-129 are in a linear relationship with their respective source term activities, the concentration for a differing source term (i.e., for a different closure date) can be calculated by multiplying the known (model predicted) concentration by the ratio of the two source term activities. This statement is true for source terms that are not greatly different from each other. Mathematically, C' = C" (A"/A') where: C = maximum groundwater concentration, A = source term activity, given that the nuclides are not solubility-limited. For uranium, because the release is solubility controlled, modest changes in the source term do not affect the resulting groundwater concentrations for uranium.
(2) (Blacklaw, 1998).

9. References

Ahmad, J, WDOH, memo to Gary Robertson, WDOH, *Results of US Ecology Manifest Audit for U-235 and U-238,* May, 2000, located in WDOH file: "USE: EIS References."

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Further Evaluation of Groundwater Concentrations for Different Covers at the US Ecology Low-Level Waste Disposal Site, Hanford Washington, Using GWSCREEN 2.5 and Minimizing the Cover's Effect at Depth

Arthur S. Rood
May 9, 2000

Introduction

US Ecology operates a commercial low-level radioactive waste disposal facility on land leased from the U.S. Department of Energy's Hanford Reservation, located near Richland Washington. This report documents refinements in estimates of radionuclide concentrations in groundwater for four different waste disposal covers. Earlier modeling (Dunkelman, 2000) determined that the nuclides of interest are: I-129, ^{99}Tc, ^{36}Cl, ^{235}U, and ^{238}U. The refinements involve the extent of an infiltration "shadow" beneath the cover and dispersion in the unsaturated zone. These calculations are in support of the dose performance assessment for this facility. The input and output files used in the evaluation are provided in Attachment A: GWSCREEN Input and Output Files.

In a previous analysis (Dunkelman, 1999), it was assumed that an infiltration "shadow" is present from the bottom of the disposal trench to the top of the aquifer. The infiltration shadow has the net effect of increasing the unsaturated transit time when the infiltration rate through the cover is less than natural recharge because of lower pore water velocities. The opposite is true when the infiltration through the cover exceeds that of natural recharge. That is, the infiltration shadow has the net effect of decreasing the unsaturated transit time. While there will probably be an infiltration shadow of some kind underneath engineered covers, the extent of it was not calculated. In this analysis, it is assumed that no infiltration "shadow" is present, resulting in unsaturated transit times comparable to that of natural recharge.

Also, in the previous analysis (Dunkelman, 1999), dispersion in the unsaturated zone was not considered because the earlier version of GWSCREEN (version 2.4a, Rood, 1994) did not include this process. GWSCREEN Version 2.5, which does include dispersion in the unsaturated zone, has since been developed. Therefore, dispersion in the unsaturated zone is included in this analysis. Effects of dispersion are discussed later in this report.

Predicted groundwater concentrations reported in this document will be used to estimate the relative effectiveness of each cover in terms of reducing concentrations of the five radionuclides in the down gradient well. The work was funded by WDOH the under contract number N08653.

Covers Modelled

Two engineered covers and two other covers were considered in this exercise. The two engineered covers are the "enhanced" cover represented by an infiltration rate of 0.5 mm yr^{-1} and the cover proposed by US Ecology represented by an infiltration rate of 2 mm yr^{-1} (Table 1). The two other covers modelled are a cover assumed to have the same infiltration rate as natural recharge, 5 mm yr^{-1} (background recharge)[1] (Wood, 1996; Kincaid, 1998); and a cover that consists of backfilled site soils with an infiltration rate of 20 mm yr^{-1} (Dunkelman, 2000). The latter cover is referred to as the site soils cover.

Table 1. Cover types, modeled unsaturated thickness, and modeled dispersivity for the evaluation of covers with no infiltration shadow

Cover Type	Infiltration ($m\ y^{-1}$)	Modeled Unsaturated Thickness (m) a	Modeled Dispersivity (m)
Enhanced	0.0005	8.23	0.4
Proposed	0.002	32.9	1.6
Background (Natural Recharge)	0.005	82.3[b]	4[b]
Site Soil (Backfill)	0.02	329	16

a. The actual depth to the water table, not including the trench depth, is 82.3 m.
b. The values for unsaturated thickness and dispersivity in the unsaturated zone used in the stochastic analysis (Rood 2000).

Conceptual Model

The conceptual model for an engineered cover (Figure 1) assumes the emplacement of a cover restricts water flow through the waste but does not restrict water movement in the unsaturated zone underlying the waste. Under these conditions, radionuclide leaching from the waste is governed by infiltration through the cover, but its movement through the unsaturated zone to the aquifer is not. That is, radionuclides move at the same rate through the unsaturated zone as if no cover was in place.

In reality, the placement of an engineered cover will certainly create an "infiltration shadow" underneath the disposal site. At depth, water infiltrating from outside the cover will migrate horizontally and eventually mix with the vertical flow of water that travelled through the cover and the waste. The vertical extent of the shadow is not known but could be estimated using additional model calculations or field studies. The conceptual model described here conservatively assumes the shadow is minimal in vertical extent. Therefore, in this conceptual model, the engineered cover only has the effect of reducing the mass flux of radionuclides through the waste and does not affect transit times in the unsaturated zone. Water fluxes in the unsaturated zone are therefore equivalent to the background infiltration rate.

[1] This "background cover" is not examined in the EIS for the Low-Level Radioactive Waste Disposal Site at Richland, Washington.

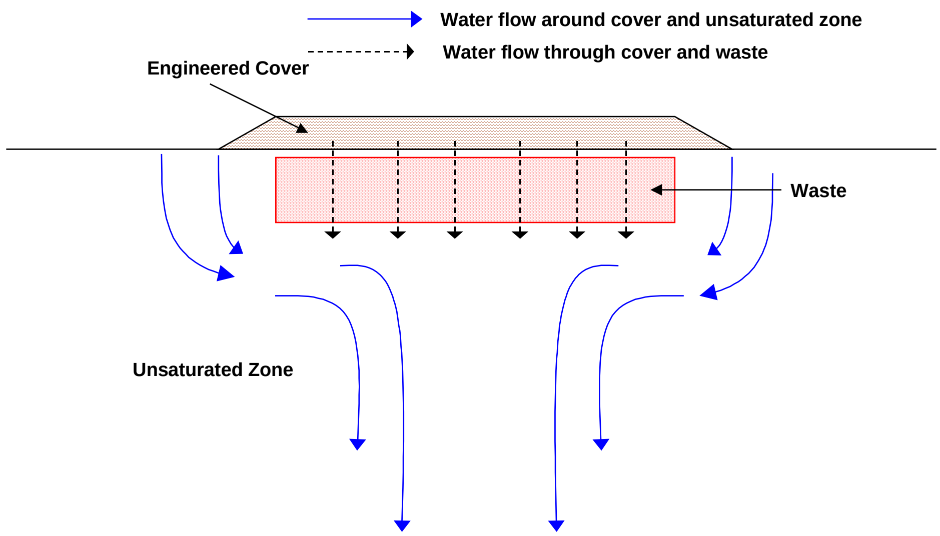

Figure 1. Conceptual model for water flow around and through an engineered cover.

For the cover representing background (or natural) recharge and for the cover representing an increase in recharge (site soils cover), there is no infiltration shadow, because there is no difference in recharge in the first case, and an excess of recharge in the second. Some of the additional water from the site soils cover will flow laterally and will eventually mix with water derived from background. Again, we have assumed that the mean water flux in the unsaturated zone is not affected In reality, the placement of an engineered cover will certainly create an "infiltration shadow" underneath the disposal site. At depth, water infiltrating from outside the cover will migrate horizontally and eventually mix with the vertical flow of water that traveled through the cover and the waste. The vertical extent of the shadow is not known but could be estimated using additional by infiltration through the cover and waste, and therefore, unsaturated transit times for the site soils cover are equivalent to the background infiltration rate. This is not a conservative assumption for the site soils cover, but was made in order to be consistent with the conceptual model.

Mathematical Model and Implementation

The GWSCREEN Version 2.5 conceptual model (Rood, 1999) does not allow for different Darcy velocities in the source and unsaturated zone. Therefore, some modifications of the input were necessary to implement the "no shadow effect" on transport of radionuclides in the unsaturated zone. The Darcy velocity in the unsaturated zone only affects the mean transit time in the unsaturated zone. While the concentrations of the leachate may change with changes in the Darcy velocity, this effect makes no difference in the aquifer model because the aquifer model uses only the mass flux from the unsaturated zone and not the leachate concentration.

Given that changes in the Darcy velocity in the unsaturated zone affects only the mean unsaturated transit time, then our goal is to adjust the transport parameters such that the water transit time reflects background infiltration and not infiltration through the site cover. The mean unsaturated transit time is given by

$$t = \frac{x\theta}{v} R_d \qquad (1)$$

where

x	=	unsaturated thickness (m)
θ	=	moisture content in unsaturated zone
v	=	Darcy velocity in unsaturated zone (m y^{-1})
R_d	=	retardation factor (nuclide specific, unit less)
t	=	mean unsaturated transit time (y).

We want to adjust one of the parameters in Equation 1 so that t is equivalent to the mean unsaturated transit time for background infiltration. Because we want to use a Darcy velocity for the waste that reflects infiltration through the cap, and we cannot change that velocity for the unsaturated zone (using the surface or buried source model), then the logical parameter to adjust is the unsaturated thickness. Solving Equation 1 for x and substituting t_{blk} for t, θ_{bkg} for θ, and v_{cover} for v, gives the unsaturated thickness to use in the simulation for a specific cover.

$$x = \frac{t_{bkg}\, v_{\mathrm{cov}er}}{\theta_{b\lg}\, R_d} \qquad (2)$$

where:

x	=	unsaturated thickness to use in the simulation for a specific cover (m)
θ_{bkg}	=	moisture content in unsaturated zone for background infiltration
v_{cover}	=	Darcy velocity through the cover (m y^{-1})
t_{bkg}	=	mean unsaturated transit time for background infiltration (y).

Mean unsaturated transit time for background infiltration was 752 years for a non-sorbing radionuclide (K_d = 0; R_d = 1) and is based on 0.005 meter/year infiltration, 82.3 meter unsaturated thickness, and 0.0457 moisture content.

GWSCREEN Version 2.5 allows for dispersion in the unsaturated zone and therefore, the unsaturated dispersivity must also be adjusted. The nominal value for unsaturated dispersivity from the stochastic analysis (Rood, 2000) was 4 meters. To simulate the same dispersion effects for different unsaturated thicknesses, the Peclet number is kept constant for each simulation. The Peclet number relates the ratio of advection to dispersion and is given by

$$Pe = \frac{x}{\alpha_L} \qquad (3)$$

where α_L = the longitudinal dispersivity (m). If the Peclet number is held constant, then the relative effect of dispersivity is preserved. The method was tested by calculating the radionuclide flux as a function of time from the disposal facility for the enhanced cover. The flux was then put into GWSCREEN as a user-defined source, the percolation rate was set at background (0.005 meter/year), and the unsaturated thickness was set at the nominal value of 82.3 meters. The testing method just described could have also been used to calculate groundwater concentrations for the stated conditions. It is more explicit than the method described by Equation 2, but also more laborious to implement. Both methods gave identical results. Unsaturated thickness and infiltration for the two cover types and background are summarised in Table 1. All other transport parameters remained the same as reported in Dunkelman, 1999.

Results and Discussion

General Observations

Concentrations as a function of time in the aquifer exhibit different shapes for the fission and activation products (^{36}Cl, ^{99}Tc, ^{129}I) and uranium isotopes (Figures 2–6). Chlorine-36 and ^{99}Tc concentrations peak before 5,000 years for all covers considered. Iodine-129 concentrations peak before 10,000 years for all covers except the enhanced cover. The concentration versus time curve for ^{129}I tended to be flatter compared to the curves for ^{36}Cl and ^{99}Tc. This effect is mainly a result of iodine sorption which retards iodine's movement in the unsaturated zone and aquifer. Iodine-129 was assigned a sorption coefficient (K_d) of 0.3 mL g^{-1} while ^{36}Cl and ^{99}Tc had K_d values of zero. Solubility limits were not a factor in the releases of any of the fission and activation products. Therefore, fission and activation product releases were controlled by first-order leaching which produces an exponentially-declining flux from the waste trench.

Concentrations of the uranium isotopes do not peak before 10,000 years and their release is governed entirely by their solubility limit. Additionally, uranium was assigned a sorption coefficient value (K_d) of 0.6 milliliter/gram which retarded its movement in the unsaturated zone and aquifer. Consequently, uranium arrives later in the 10,000-year compliance period compared to the fission and activation products. The solubility-limited release results in a steady-state flux from the waste trench lasting until the pore water concentration in the waste trench drops below the solubility limit of uranium (1 milligram/liter). The solubility-limited release was estimated to last over 1×10^6 years. The concentration of uranium isotopes in the aquifer reached a steady-state value after about 30,000 years. Therefore, concentrations were still rising at the end of the 10,000-year compliance period. It is also worth mentioning that the ^{235}U concentration is higher than the ^{238}U concentration despite the fact that the ^{238}U inventory was greater than ^{235}U. The higher ^{235}U concentration is because ^{235}U has a higher specific activity than ^{238}U[2].

Differences in Cover Effectiveness

As expected, the enhanced cover resulted in the lowest concentrations of radionuclides in the aquifer followed by the proposed, background, and site soils cover (Table 2). Differences in the peak concentrations between the covers were related to the estimated infiltration rate. For the fission and activation products, a factor of 10 reduction in the infiltration rate (between the background and enhanced cover) resulted in about a factor of 2 reduction in the peak aquifer concentration. However, for the uranium isotopes, a factor of 10 reduction in the infiltration rate (between the background and

[2] Specific activities of ^{235}U and ^{238}U are 2.16 nCi g^{-1} and 0.335 nCi g^{-1} respectively.

enhanced cover) resulted in a factor of 10 reduction in the peak aquifer concentration. In other words, for the uranium isotopes the peak aquifer concentration at 10,000 years was proportional to the infiltration rate through the cover. The difference between the relative effectiveness of each cover on the fission and activation product groundwater concentrations and the uranium isotope groundwater concentrations is attributed to the fact that the uranium concentrations had not peaked in the 10,000-year compliance window. Had the compliance window been longer (i.e., much greater than 10,000 years), uranium isotope groundwater concentrations would have responded to the various covers in a manner similar to that of the fission and activation product groundwater concentrations.

In Figure 2, concentrations of ^{36}Cl and ^{99}Tc versus time for the enhanced cover exhibit long tails which overlap with contaminant plumes for^{129}I, ^{235}U, and ^{238}U. For the proposed cover (Figure 3), concentrations of ^{36}Cl and ^{99}Tc drop off relatively rapidly, and are less than 10^{-13} Ci m^{-3} (1×10^{-4} pCi L^{-1}) around 4,000 years. The long tails observed for ^{36}Cl and ^{99}Tc for the enhanced cover reflect the slower, but longer release rate from waste. The same is true for ^{129}I but the curve extends well after the 10,000-year compliance period. The uranium curves are governed by their solubility limit which results in a steady-state release for times exceeding 1×10^6 years. The peak concentration is not achieved within the 10,000-year time of compliance. The implication of the overlap of the 5 nuclides depends on the relative values of the nuclide-specific dose conversion factors, and is described in Thatcher, 2000.

Table 3 shows a comparison between the site soils cover with and without the infiltration shadow. Concentrations are considerably higher assuming a shadow because infiltration is higher than natural recharge. Again, the uranium isotopes exhibit the greatest change (greater than 10 times) while the other nuclides (I-129, Tc-99, and Cl-36) exhibited about a factor of 4 change between the “with” and “without" shadow results.

Table 2. Maximum (peak) groundwater concentrations) and time of maximum concentration for the various covers examined. If the time of maximum exceeded 10,000 years, then the concentration at 10,000 years is reported.

	Enhanced Cover 0.5 mm y^{-1} (pCi L^{-1} [years])	Proposed Cover 2 mm y^{-1} (pCi L^{-1} [years])	Background Cover 5 mm y^{-1} (pCi L^{-1} [years])	Site Soils Cover 20 mm y^{-1} (pCi L^{-1} [years])
^{129}I	1.9 [10,000]	3.9 [9750]	4.6 [8750]	4.9 [8,000]
^{99}Tc	270 [1,000]	490[900]	570 [800]	630 [700]
^{36}Cl	20 [1,000]	36 [900]	42 [800]	46 [700]
^{235}U	0.057 [10,000]	0.23 [10,000]	0.57 [10,000]	2.3 [10,000]
^{238}U	0.0089 [10,000]	0.036 [10,000]	0.089 [10,000]	0.36 [10,000]

Table 3. Results of Site Soils Cover Comparison, With and Without Infiltration Shadow

Nuclide	Without Shadow (pCi/L)	With Shadow (pCi/L)
I-129	4.9	18
Tc-99	630	2300
Cl-36	46	170
U-235	2.3	45
U-238	0.36	7

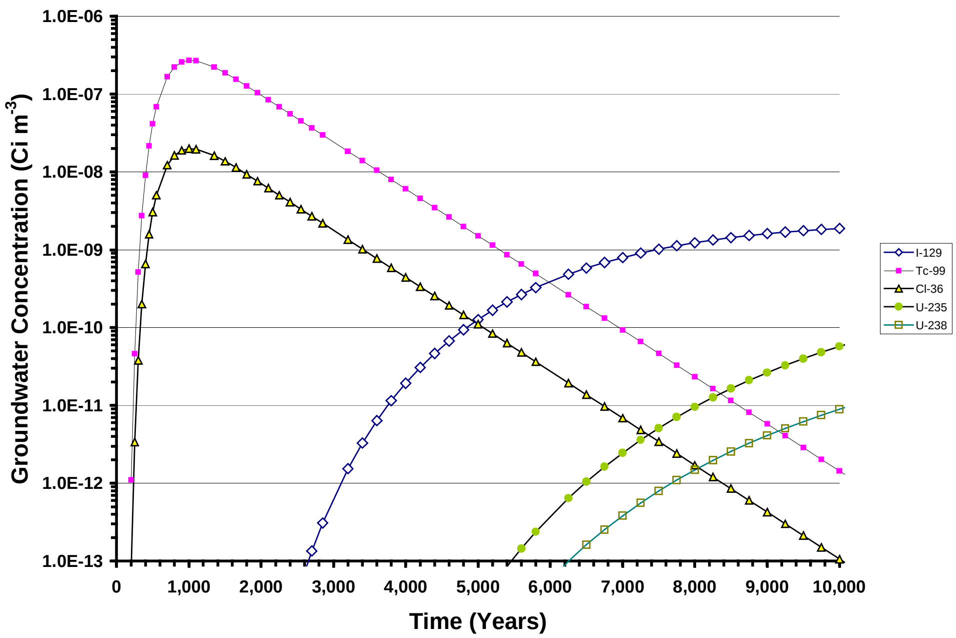

Figure 2. Concentration as a function of time for the enhanced cover

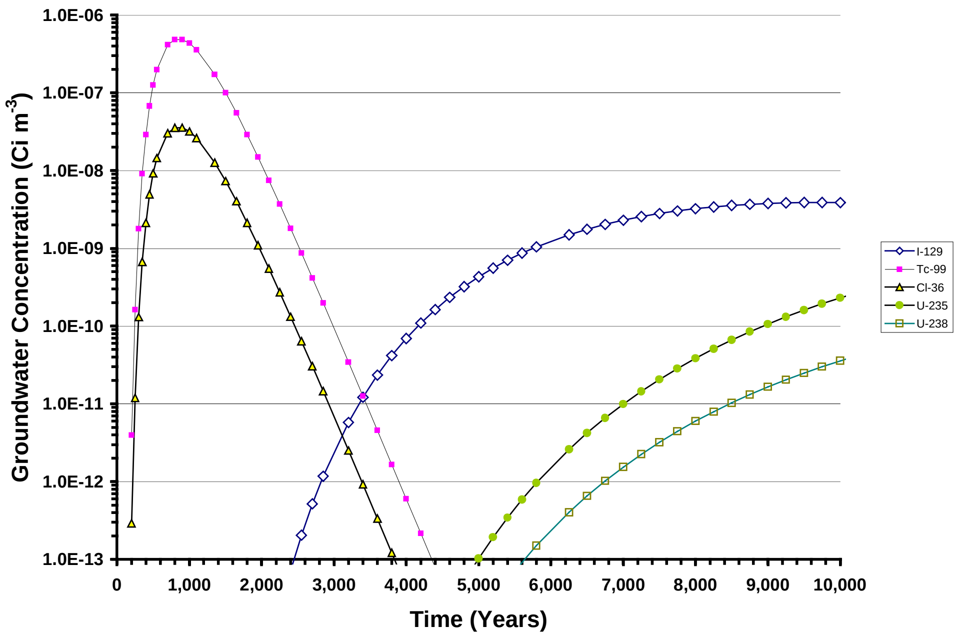

Figure 3. Concentration as a function of time in the aquifer for the proposed cover.

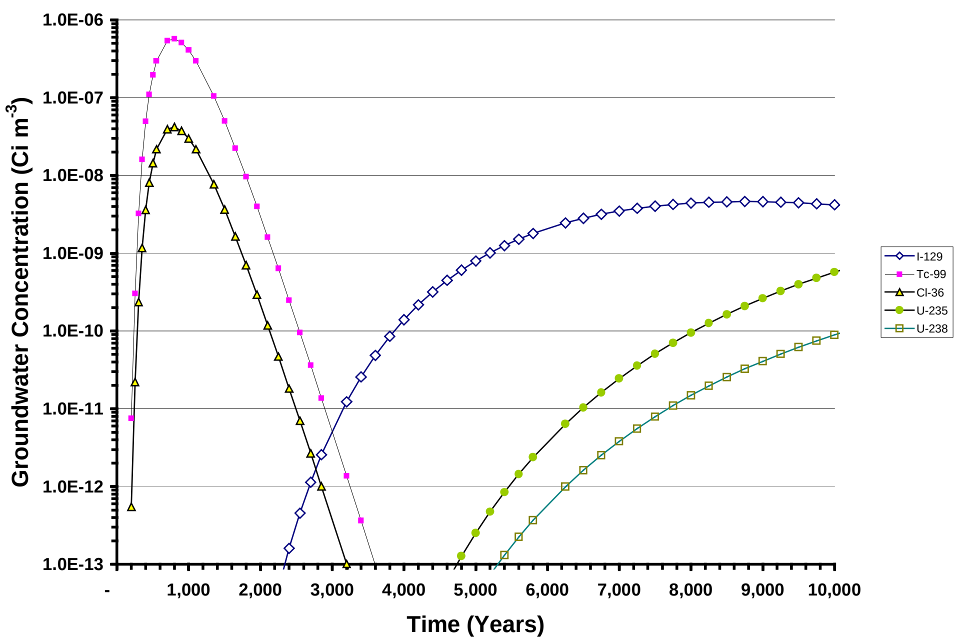

Figure 4. Concentration as a function of time for the background cover.

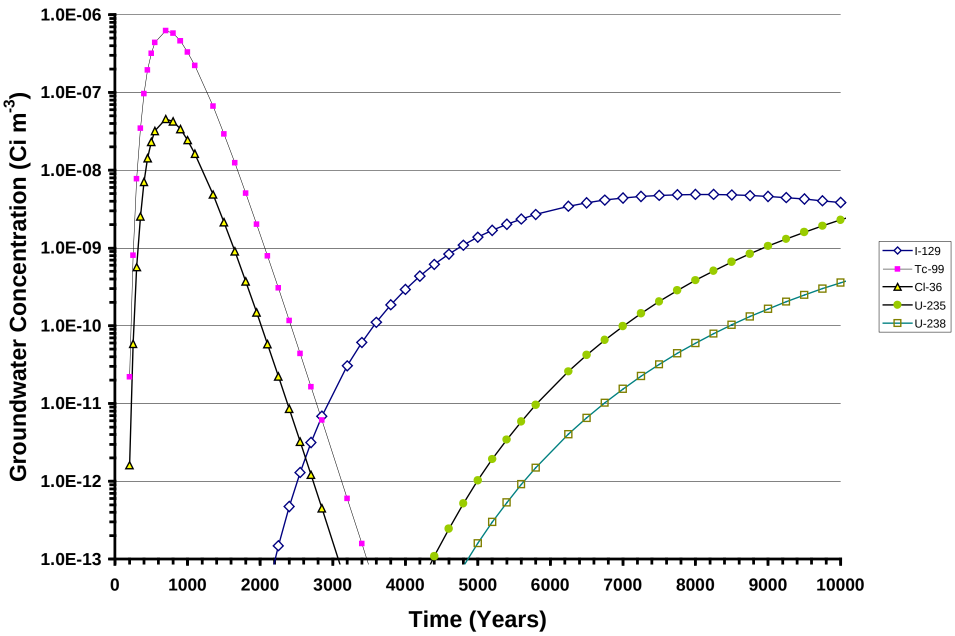

Figure 5. Concentration as a function of time for the site soils cover.

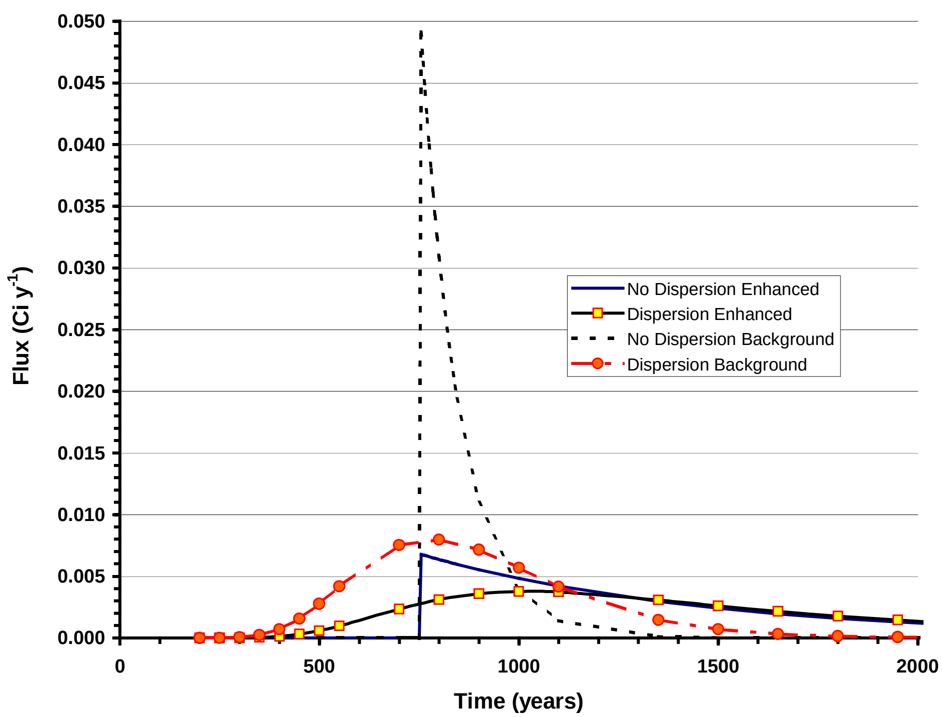

Figure 6. Total flux of ^{36}Cl to the aquifer as a function of time for the enhanced and background cover with and without dispersion in the unsaturated zone.

Implications of the Infiltration Shadow and Unsaturated Dispersivity

The calculations report in this document differ from those reported in Dunkelman, 1999 in that the assumption of an infinite infiltration shadow and no dispersion in the unsaturated zone were altered. In these calculations, the infiltration shadow was assumed to be minimal and dispersion was considered in the unsaturated zone. Both these processes had an impact on the estimated concentrations in the groundwater. In general, the assumption of a minimal infiltration shadow results in unsaturated water transit times that are identical regardless of the cover applied. The inclusion of dispersivity in the unsaturated zone has the net effect of reducing peak aquifer concentrations and shortening the contaminant arrival times in the aquifer. The effects of dispersivity in the unsaturated zone are illustrated in Figure 6, which shows the mass flux to the aquifer of ^{36}Cl for the enhanced and background covers with and without dispersivity. The first thing to note in Figure 6 is that the peak flux to the aquifer is higher for the cases of no dispersion compared to cases with dispersion. However, also note that the ^{36}Cl arrives at the aquifer sooner in the cases where dispersion is considered. Second, it is important to note the relative difference in the peak aquifer flux for the different covers with and without dispersion. Take for example the difference in the peak aquifer flux for the enhanced and background cover when dispersion is not considered. The peak aquifer flux is approximately 0.05 Curies/year for the background cover and approximately 0.006 Curies/year for the enhanced cover. This equates to a factor of 8 difference in the peak aquifer flux for a factor of 10 difference in the infiltration. Now observe the peak aquifer flux for the case with dispersion. The peak aquifer flux is approximately 0.008 Curies/year for the background cover and approximately 0.004 Curies/year for the enhanced cover. This equates to a factor of 2 difference in the peak aquifer flux for a factor of 10 difference in the infiltration. Therefore, dispersion tends to “damp out” the effects of large changes in the infiltration between the two covers.

Dispersion is a well-known process in groundwater contaminant transport, and was excluded from GWSCREEN Version 2.4a for the convenience of the calculation. As was shown in Figure 6, a no-dispersion model can provide a conservative estimate of peak aquifer flux to the groundwater, however, the time of arrival is somewhat distorted, and must be interpreted with caution when comparing to regulatory standards that incorporate a time-of-compliance window. For 36Cl and 99Tc, the results for the no-dispersion model were certainly conservative for all covers considered. For the other nuclides (129I, 235U, 238U), the no dispersion model is not conservative within the time frame because the mean arrival times of the contaminant plume exceeded 10,000 years in most cases.

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Appendix A: GWSCREEN Input and Output Files

Enhanced Cover Input File

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Washington State PA Enhanced Cover 0.0005 m/y and no shadow            (Card 1)
1 1 0 2 1                             (Card 2) imode,itype,idisp,kflag idil
1 2 2 1 1                             (Card 3) imodel,isolve,isolveu,imoist,imoistu
$ I have fixed the moisture content to reflect the published values
6 12 0.001                            (Card 4) jstart jmax eps
70. 2.555E+04 2.0  365.  1.  0.025    (Card 5) bw,at,wi,ef,ed,dlim
0.  0.                                (Card 6) x0,y0
518.  382.  0.0005                      (Card 7) l,w,perc
10.6 1.26                             (Card 8b) thicks,rhos
0.034                                 (Card 8c) thetas
$ 7.51  2.298 1710. 0.2724 0.0321       (Card 8d) alpha n ksat pors thetar
8.23  1.6  0.4                         (Card 9) depth,rhou,axu
$ The depth has been adjusted so the VZWTT is the same as background
$ infiltration (0.005 m/y)
$7.51  2.298 1710. 0.2724 0.0321       (Card 9b) alpha n ksat pors thetar
0.0457                                 (Card 9c) thetau
27.5  5.  5.0e-1   15.  15.           (Card 10) ax,ay,az,b,z
32.9  0.1  1.6                        (Card 11) u,phi,rhoa
1                                     (Card 12a nrecept
275.  0.                              (Card 12b) xrec(i) yrec(i)
6                                     (Card 13a)
200.  600.  50.                      (Card 13b)
700.  1200. 100.
1350. 3000. 150.
3200. 6000. 200.
6250. 10500. 250.
11000. 30000. 1000.
5                                     (Card 14) ncontam
$ I-129
0  0.3 0.3  129.  6.012  0.0 1.0e6 0.0 (Card 14a) nprog kds kdu zmw q0 rmi sl other
I-129 1.57E7 0.3 2.76e5                (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ Tc-99
0   0.0  0.0  99. 67.1   0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Tc-99 2.10E5 0.0 1460.                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ CL-36
0   0.0  0.0  36. 4.907  0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Cl-36 3.01E5 0.0 3030                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-235
2   0.6 0.6 235. 1.468E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-235  7.04E8 0.6 2.67e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pa-231 3.28E4 0.6 1.06e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ac-227 2.17E1 100. 1.48e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-238
4   0.6 0.6 238. 2.228E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-238  4.47E9 0.6 2.69e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
U-234  2.44E5 0.6 2.83e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Th-230 7.70E4 40. 5.48e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ra-226 1.60E3 8.  1.33e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pb-210 2.23E1 2000. 7.27e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
```

Enhanced Cover Output File

```
 TIME OF RUN: 16:20:27.23  DATE OF RUN: 03/02/00
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                  GWSCREEN                       *
   *                 Version 2.5a                    *
```

```
  *    A semi-analytical model for the assessment   *
  *    of the groundwater pathway from the leaching *
  *    of surficial and buried contamination and    *
  *  release of contaminants from percolation ponds *
  *                 01/04/2000                      *
  *                Arthur S. Rood                   *
  *         Idaho National Engineering and          *
  *            Environmental Laboratory             *
  *                 PO Box 1625                     *
  *             Idaho Falls, Idaho 83415            *
  **************************************************
 ============================================================================
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                   LIMITATION OF LIABILITY

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 DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
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 ===========================================================================

OUTPUT FILE NAME: ecover.out
INPUT FILE NAME: ecover.par
Title: Washington State PA Enhanced Cover 0.0005 m/y and no shadow            (Card 1)
-----------------------------------------------------------------------------
Model Run Options
-----------------------------------------------------------------------------
IMODE Contaminant Type and Impacts:                             1
ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                     1
IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:           0
KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:            2
IDIL (1) No dilution factor (2) Include Dilution Factor:        1
IMOIST Source Moisture Content Option:                          1
IMOISTU Unsaturated Moisture Content Option:                    1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:            1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)      2
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  2
JSTART:   6
JMAX  :  12
EPS   :  1.000E-03
Health Effects: Committed effective dose equivalent calculation
Output mass/activity units:   Ci
Output concentration units:   Ci/m**3
Dose/Risk Conversion Units:   rem/Ci
Output health effects units:  rem
-----------------------------------------------------------------------------
Exposure Parameters
-----------------------------------------------------------------------------
Body Mass (kg):             70.       Averaging Time (days):      25550.
Water Ingestion (L/d):      2.000E+00 Exposure Freq (day/year):   3.650E+02
Exposure Duration (y):      1.000E+00 Limiting Dose:              2.500E-02
-----------------------------------------------------------------------------
Site Parameters
-----------------------------------------------------------------------------
X Coordinate:               0.000E+00  Y Coordinate:               0.000E+00
Source Length (m):          5.180E+02  Source Width (m):           3.820E+02
Percolation Rate (m/y):     5.000E-04
Source Thickness (m):       1.060E+01  Src Bulk Density (g/cc):    1.260E+00
Source Moisture Content:    3.400E-02
-----------------------------------------------------------------------------
```

```
Unsaturated Zone Parameters
-----------------------------------------------------------------------------
Unsat Zone Thickness (m):    8.230E+00  Unsat Bulk Density:         1.600E+00
Unsat Dispersivity (m):      4.000E-01  Unsat Moisture Content:     4.570E-02
-----------------------------------------------------------------------------
Aquifer Zone Parameters
-----------------------------------------------------------------------------
Longitudinal Disp (m):       2.750E+01  Transverse Disp (m):        5.000E+00
Aquifer Thickness (m):       1.500E+01  Well Screen Thickness (m):  1.500E+01
Darcy Velocity (m/y):        3.290E+01  Aquifer Porosity:           1.000E-01
Bulk Density (g/cc):         1.600E+00
-----------------------------------------------------------------------------
Calculated Flow Parameters
-----------------------------------------------------------------------------
Percolation Water Flux (m3/y):  9.8938E+01
Unsat Pore Velocity (m/y):      1.0941E-02
Aquifer Pore Velocity (m/y):    3.2900E+02
Longitudinal Disp (m**2/y):     9.0475E+03
Transverse Disp (m**2/y):       1.6450E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:               I-129
 Number of Progeny:              0
 Half Life (y):                  1.570E+07
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):               3.000E-01
 Solubility Limit (mg/L):        1.000E+06
 Molecular Weight (mg/L):        1.290E+02
 Initial mass/activity:          6.012E+00
 Kd Unsat (ml/g):                3.000E-01
 Kd Aquifer (ml/g):              3.000E-01
 Risk/Dose Conversion Factor:    2.760E+05
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    4.4150E-08
Leach Rate Constant (1/y):                1.1449E-04
Initial Pore Water Conc (Ci or mg/m**3):  6.9570E-06
Solubility Limited Mass (mg):             8.6416E+14
Solubility Limited Act (Ci):              1.5266E+08
Unsaturated Retardation Factor:           1.1503E+01
Mean Unsaturated Transit Time (y):        8.6530E+03
Leading Edge Arrival Time (y):            1.3087E+03
Aquifer Retardation Factor:               5.800E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00
 8.0000E+02  3.505E-25  0.000E+00
 9.0000E+02  1.739E-22  0.000E+00
 1.0000E+03  2.454E-20  0.000E+00
 1.1000E+03  1.402E-18  0.000E+00
 1.3500E+03  2.471E-15  1.137E-20
 1.5000E+03  6.547E-14  3.092E-19
 1.6500E+03  9.481E-13  4.565E-18
 1.8000E+03  8.723E-12  4.263E-17
 1.9500E+03  5.660E-11  2.798E-16
 2.1000E+03  2.791E-10  1.393E-15
```

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 2.2500E+03  1.105E-09  5.554E-15
 2.4000E+03  3.657E-09  1.850E-14
 2.5500E+03  1.045E-08  5.312E-14
 2.7000E+03  2.640E-08  1.348E-13
 2.8500E+03  6.016E-08  3.083E-13
 3.2000E+03  2.983E-07  1.539E-12
 3.4000E+03  6.343E-07  3.282E-12
 3.6000E+03  1.230E-06  6.380E-12
 3.8000E+03  2.207E-06  1.147E-11
 4.0000E+03  3.707E-06  1.930E-11
 4.2000E+03  5.882E-06  3.067E-11
 4.4000E+03  8.889E-06  4.641E-11
 4.6000E+03  1.287E-05  6.730E-11
 4.8000E+03  1.796E-05  9.400E-11
 5.0000E+03  2.426E-05  1.271E-10
 5.2000E+03  3.183E-05  1.668E-10
 5.4000E+03  4.070E-05  2.135E-10
 5.6000E+03  5.087E-05  2.670E-10
 5.8000E+03  6.229E-05  3.271E-10
 6.2500E+03  9.210E-05  4.842E-10
 6.5000E+03  1.107E-04  5.824E-10
 6.7500E+03  1.304E-04  6.863E-10
 7.0000E+03  1.509E-04  7.944E-10
 7.2500E+03  1.718E-04  9.048E-10
 7.5000E+03  1.928E-04  1.016E-09
 7.7500E+03  2.136E-04  1.126E-09
 8.0000E+03  2.340E-04  1.233E-09
 8.2500E+03  2.535E-04  1.336E-09
 8.5000E+03  2.721E-04  1.435E-09
 8.7500E+03  2.896E-04  1.527E-09
 9.0000E+03  3.058E-04  1.613E-09
 9.2500E+03  3.206E-04  1.691E-09
 9.5000E+03  3.339E-04  1.762E-09
 9.7500E+03  3.458E-04  1.825E-09
 1.0000E+04  3.562E-04  1.880E-09
 1.0250E+04  3.650E-04  1.927E-09
 1.1000E+04  3.831E-04  2.023E-09
 1.2000E+04  3.897E-04  2.058E-09
 1.3000E+04  3.810E-04  2.012E-09
 1.4000E+04  3.623E-04  1.914E-09
 1.5000E+04  3.377E-04  1.784E-09
 1.6000E+04  3.104E-04  1.640E-09
 1.7000E+04  2.826E-04  1.493E-09
 1.8000E+04  2.556E-04  1.351E-09
 1.9000E+04  2.301E-04  1.216E-09
 2.0000E+04  2.065E-04  1.091E-09
 2.1000E+04  1.849E-04  9.771E-10
 2.2000E+04  1.653E-04  8.737E-10
 2.3000E+04  1.477E-04  7.805E-10
 2.4000E+04  1.319E-04  6.969E-10
 2.5000E+04  1.177E-04  6.219E-10
 2.6000E+04  1.050E-04  5.549E-10
 2.7000E+04  9.367E-05  4.950E-10
 2.8000E+04  8.355E-05  4.415E-10
 2.9000E+04  7.452E-05  3.938E-10
Maximum Concentration and Time for Member #1:  2.058E-09  1.200E+04
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:              Tc-99
 Number of Progeny:             0
 Half Life (y):                 2.100E+05
 Other Source Loss Rate (1/y):  0.000E+00
 Kd Source (ml/g):              0.000E+00
 Solubility Limit (mg/L):       1.000E+06
 Molecular Weight (mg/L):       9.900E+01
 Initial mass/activity:         6.710E+01
 Kd Unsat (ml/g):               0.000E+00
 Kd Aquifer (ml/g):             0.000E+00
 Risk/Dose Conversion Factor:   1.460E+03
```

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-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    3.3007E-06
Leach Rate Constant (1/y):                1.3873E-03
Initial Pore Water Conc (Ci or mg/m**3):  9.4090E-04
Solubility Limited Mass (mg):             7.1315E+13
Solubility Limited Act (Ci):              1.2273E+09
Unsaturated Retardation Factor:           1.0000E+00
Mean Unsaturated Transit Time (y):        7.5222E+02
Leading Edge Arrival Time (y):            1.1377E+02
Aquifer Retardation Factor:               1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  2.277E-07  1.096E-12
 2.5000E+02  9.273E-06  4.621E-11
 3.0000E+02  1.022E-04  5.188E-10
 3.5000E+02  5.325E-04  2.736E-09
 4.0000E+02  1.739E-03  8.998E-09
 4.5000E+02  4.156E-03  2.162E-08
 5.0000E+02  7.991E-03  4.172E-08
 5.5000E+02  1.312E-02  6.871E-08
 7.0000E+02  3.187E-02  1.677E-07
 8.0000E+02  4.241E-02  2.235E-07
 9.0000E+02  4.895E-02  2.583E-07
 1.0000E+03  5.144E-02  2.716E-07
 1.1000E+03  5.077E-02  2.682E-07
 1.3500E+03  4.202E-02  2.221E-07
 1.5000E+03  3.548E-02  1.876E-07
 1.6500E+03  2.938E-02  1.554E-07
 1.8000E+03  2.409E-02  1.274E-07
 1.9500E+03  1.965E-02  1.039E-07
 2.1000E+03  1.599E-02  8.456E-08
 2.2500E+03  1.300E-02  6.872E-08
 2.4000E+03  1.055E-02  5.581E-08
 2.5500E+03  8.569E-03  4.532E-08
 2.7000E+03  6.957E-03  3.679E-08
 2.8500E+03  5.647E-03  2.986E-08
 3.2000E+03  3.471E-03  1.836E-08
 3.4000E+03  2.628E-03  1.390E-08
 3.6000E+03  1.990E-03  1.052E-08
 3.8000E+03  1.507E-03  7.969E-09
 4.0000E+03  1.141E-03  6.034E-09
 4.2000E+03  8.640E-04  4.569E-09
 4.4000E+03  6.542E-04  3.460E-09
 4.6000E+03  4.954E-04  2.620E-09
 4.8000E+03  3.751E-04  1.984E-09
 5.0000E+03  2.840E-04  1.502E-09
 5.2000E+03  2.151E-04  1.137E-09
 5.4000E+03  1.628E-04  8.611E-10
 5.6000E+03  1.233E-04  6.521E-10
 5.8000E+03  9.337E-05  4.937E-10
 6.2500E+03  4.994E-05  2.641E-10
 6.5000E+03  3.527E-05  1.865E-10
 6.7500E+03  2.491E-05  1.317E-10
 7.0000E+03  1.760E-05  9.306E-11
 7.2500E+03  1.243E-05  6.573E-11
 7.5000E+03  8.777E-06  4.642E-11
 7.7500E+03  6.202E-06  3.279E-11
 8.0000E+03  4.380E-06  2.316E-11
 8.2500E+03  3.094E-06  1.636E-11
 8.5000E+03  2.185E-06  1.156E-11
 8.7500E+03  1.544E-06  8.163E-12
 9.0000E+03  1.090E-06  5.766E-12
 9.2500E+03  7.701E-07  4.073E-12
 9.5000E+03  5.440E-07  2.877E-12
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 9.7500E+03  3.842E-07  2.032E-12
 1.0000E+04  2.714E-07  1.435E-12
 1.0250E+04  1.917E-07  1.014E-12
 1.1000E+04  6.756E-08  3.572E-13
 1.2000E+04  1.682E-08  8.892E-14
 1.3000E+04  4.186E-09  2.213E-14
 1.4000E+04  1.042E-09  5.509E-15
 1.5000E+04  2.593E-10  1.371E-15
 1.6000E+04  6.455E-11  3.414E-16
 1.7000E+04  1.607E-11  8.497E-17
 1.8000E+04  3.999E-12  2.115E-17
 1.9000E+04  9.955E-13  5.264E-18
 2.0000E+04  2.478E-13  1.310E-18
 2.1000E+04  6.168E-14  3.262E-19
 2.2000E+04  1.535E-14  8.119E-20
 2.3000E+04  3.822E-15  2.021E-20
 2.4000E+04  9.513E-16  5.030E-21
 2.5000E+04  2.368E-16  1.252E-21
 2.6000E+04  5.894E-17  3.117E-22
 2.7000E+04  1.467E-17  7.758E-23
 2.8000E+04  3.652E-18  1.931E-23
 2.9000E+04  9.090E-19  4.807E-24
Maximum Concentration and Time for Member #1:  2.716E-07  1.000E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:              Cl-36
 Number of Progeny:             0
 Half Life (y):                 3.010E+05
 Other Source Loss Rate (1/y):  0.000E+00
 Kd Source (ml/g):              0.000E+00
 Solubility Limit (mg/L):       1.000E+06
 Molecular Weight (mg/L):       3.600E+01
 Initial mass/activity:         4.907E+00
 Kd Unsat (ml/g):               0.000E+00
 Kd Aquifer (ml/g):             0.000E+00
 Risk/Dose Conversion Factor:   3.030E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                  2.3028E-06
Leach Rate Constant (1/y):              1.3873E-03
Initial Pore Water Conc (Ci or mg/m**3):  6.8808E-05
Solubility Limited Mass (mg):           7.1315E+13
Solubility Limited Act (Ci):            2.3547E+09
Unsaturated Retardation Factor:         1.0000E+00
Mean Unsaturated Transit Time (y):      7.5222E+02
Leading Edge Arrival Time (y):          1.1377E+02
Aquifer Retardation Factor:             1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  1.665E-08  8.017E-14
 2.5000E+02  6.783E-07  3.380E-12
 3.0000E+02  7.473E-06  3.795E-11
 3.5000E+02  3.896E-05  2.001E-10
 4.0000E+02  1.272E-04  6.583E-10
 4.5000E+02  3.041E-04  1.582E-09
 5.0000E+02  5.847E-04  3.053E-09
 5.5000E+02  9.603E-04  5.028E-09
 7.0000E+02  2.332E-03  1.227E-08
 8.0000E+02  3.104E-03  1.636E-08
 9.0000E+02  3.583E-03  1.890E-08
 1.0000E+03  3.766E-03  1.988E-08
 1.1000E+03  3.717E-03  1.964E-08
 1.3500E+03  3.077E-03  1.627E-08
 1.5000E+03  2.598E-03  1.374E-08
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 1.6500E+03  2.152E-03  1.138E-08
 1.8000E+03  1.765E-03  9.333E-09
 1.9500E+03  1.440E-03  7.615E-09
 2.1000E+03  1.172E-03  6.197E-09
 2.2500E+03  9.525E-04  5.037E-09
 2.4000E+03  7.737E-04  4.091E-09
 2.5500E+03  6.283E-04  3.322E-09
 2.7000E+03  5.101E-04  2.698E-09
 2.8500E+03  4.142E-04  2.190E-09
 3.2000E+03  2.547E-04  1.347E-09
 3.4000E+03  1.929E-04  1.020E-09
 3.6000E+03  1.461E-04  7.724E-10
 3.8000E+03  1.106E-04  5.850E-10
 4.0000E+03  8.378E-05  4.430E-10
 4.2000E+03  6.345E-05  3.355E-10
 4.4000E+03  4.805E-05  2.541E-10
 4.6000E+03  3.639E-05  1.925E-10
 4.8000E+03  2.756E-05  1.458E-10
 5.0000E+03  2.087E-05  1.104E-10
 5.2000E+03  1.581E-05  8.360E-11
 5.4000E+03  1.197E-05  6.332E-11
 5.6000E+03  9.068E-06  4.795E-11
 5.8000E+03  6.868E-06  3.632E-11
 6.2500E+03  3.675E-06  1.943E-11
 6.5000E+03  2.596E-06  1.373E-11
 6.7500E+03  1.834E-06  9.700E-12
 7.0000E+03  1.296E-06  6.853E-12
 7.2500E+03  9.156E-07  4.842E-12
 7.5000E+03  6.467E-07  3.420E-12
 7.7500E+03  4.570E-07  2.417E-12
 8.0000E+03  3.229E-07  1.708E-12
 8.2500E+03  2.281E-07  1.206E-12
 8.5000E+03  1.612E-07  8.523E-13
 8.7500E+03  1.139E-07  6.022E-13
 9.0000E+03  8.046E-08  4.255E-13
 9.2500E+03  5.684E-08  3.006E-13
 9.5000E+03  4.016E-08  2.124E-13
 9.7500E+03  2.837E-08  1.500E-13
 1.0000E+04  2.005E-08  1.060E-13
 1.0250E+04  1.416E-08  7.490E-14
 1.1000E+04  4.995E-09  2.641E-14
 1.2000E+04  1.245E-09  6.581E-15
 1.3000E+04  3.101E-10  1.640E-15
 1.4000E+04  7.726E-11  4.086E-16
 1.5000E+04  1.925E-11  1.018E-16
 1.6000E+04  4.797E-12  2.536E-17
 1.7000E+04  1.195E-12  6.320E-18
 1.8000E+04  2.978E-13  1.575E-18
 1.9000E+04  7.420E-14  3.924E-19
 2.0000E+04  1.849E-14  9.776E-20
 2.1000E+04  4.606E-15  2.436E-20
 2.2000E+04  1.148E-15  6.069E-21
 2.3000E+04  2.860E-16  1.512E-21
 2.4000E+04  7.125E-17  3.768E-22
 2.5000E+04  1.775E-17  9.388E-23
 2.6000E+04  4.423E-18  2.339E-23
 2.7000E+04  1.102E-18  5.828E-24
 2.8000E+04  2.746E-19  1.452E-24
 2.9000E+04  6.842E-20  3.618E-25
Maximum Concentration and Time for Member #1:  1.988E-08  1.000E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                U-235
 Number of Progeny:               2
 Progeny Names:                  Pa-231       Ac-227
 Half Life (y):                   7.040E+08 3.280E+04 2.170E+01
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):                6.000E-01
 Solubility Limit (mg/L):         1.000E+00
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 Molecular Weight (mg/L):        2.350E+02
 Initial mass/activity:          1.468E+04
 Kd Unsat (ml/g):                6.000E-01
 Kd Aquifer (ml/g):              6.000E-01 6.000E-01 1.000E+02
 Risk/Dose Conversion Factor:    2.670E+05 1.060E+03 1.480E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    9.8458E-10 2.1133E-05 3.1942E-02
Leach Rate Constant (1/y):                5.9709E-05
Initial Pore Water Conc (Ci or mg/m**3):  8.8593E-03
Solubility Limited Mass (mg):             1.6570E+09
Solubility Limited Act (Ci):              3.5836E+00
Solubility Limited Time (y):              6.6373E+07
Unsaturated Retardation Factor:           2.2007E+01
Mean Unsaturated Transit Time (y):        1.6554E+04
Leading Edge Arrival Time (y):            2.5037E+03
Aquifer Retardation Factor:               1.060E+01 1.060E+01 1.601E+03
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 8.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 9.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.0000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.1000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.3500E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.5000E+03  3.408E-26  0.000E+00  0.000E+00  0.000E+00
 1.6500E+03  6.282E-24  0.000E+00  0.000E+00  0.000E+00
 1.8000E+03  4.660E-22  0.000E+00  0.000E+00  0.000E+00
 1.9500E+03  1.777E-20  0.000E+00  0.000E+00  0.000E+00
 2.1000E+03  4.018E-19  0.000E+00  0.000E+00  0.000E+00
 2.2500E+03  5.979E-18  0.000E+00  0.000E+00  0.000E+00
 2.4000E+03  6.332E-17  0.000E+00  0.000E+00  0.000E+00
 2.5500E+03  5.068E-16  2.338E-21  1.227E-22  8.024E-25
 2.7000E+03  3.211E-15  1.503E-20  8.336E-22  5.457E-24
 2.8500E+03  1.671E-14  7.919E-20  4.629E-21  3.032E-23
 3.2000E+03  4.262E-13  2.065E-18  1.351E-19  8.857E-22
 3.4000E+03  2.000E-12  9.790E-18  6.787E-19  4.454E-21
 3.6000E+03  7.876E-12  3.887E-17  2.847E-18  1.869E-20
 3.8000E+03  2.675E-11  1.329E-16  1.026E-17  6.738E-20
 4.0000E+03  8.011E-11  4.006E-16  3.247E-17  2.134E-19
 4.2000E+03  2.154E-10  1.083E-15  9.196E-17  6.045E-19
 4.4000E+03  5.277E-10  2.664E-15  2.366E-16  1.556E-18
 4.6000E+03  1.192E-09  6.042E-15  5.597E-16  3.682E-18
 4.8000E+03  2.508E-09  1.276E-14  1.231E-15  8.098E-18
 5.0000E+03  4.959E-09  2.530E-14  2.537E-15  1.670E-17
 5.2000E+03  9.276E-09  4.746E-14  4.939E-15  3.251E-17
 5.4000E+03  1.652E-08  8.473E-14  9.138E-15  6.017E-17
 5.6000E+03  2.816E-08  1.447E-13  1.615E-14  1.064E-16
 5.8000E+03  4.615E-08  2.377E-13  2.742E-14  1.806E-16
 6.2500E+03  1.239E-07  6.402E-13  7.921E-14  5.220E-16
 6.5000E+03  2.010E-07  1.041E-12  1.336E-13  8.806E-16
 6.7500E+03  3.137E-07  1.627E-12  2.163E-13  1.426E-15
 7.0000E+03  4.727E-07  2.455E-12  3.376E-13  2.226E-15
 7.2500E+03  6.901E-07  3.589E-12  5.098E-13  3.362E-15
 7.5000E+03  9.795E-07  5.099E-12  7.474E-13  4.929E-15
 7.7500E+03  1.355E-06  7.062E-12  1.067E-12  7.037E-15
 8.0000E+03  1.832E-06  9.555E-12  1.486E-12  9.805E-15
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  8.2500E+03  2.425E-06  1.266E-11  2.025E-12  1.336E-14
  8.5000E+03  3.148E-06  1.645E-11  2.705E-12  1.785E-14
  8.7500E+03  4.017E-06  2.100E-11  3.546E-12  2.340E-14
  9.0000E+03  5.044E-06  2.639E-11  4.571E-12  3.017E-14
  9.2500E+03  6.241E-06  3.267E-11  5.801E-12  3.829E-14
  9.5000E+03  7.618E-06  3.990E-11  7.258E-12  4.791E-14
  9.7500E+03  9.184E-06  4.813E-11  8.962E-12  5.916E-14
  1.0000E+04  1.094E-05  5.738E-11  1.093E-11  7.217E-14
  1.0250E+04  1.290E-05  6.768E-11  1.318E-11  8.703E-14
  1.1000E+04  1.999E-05  1.049E-10  2.177E-11  1.438E-13
  1.2000E+04  3.210E-05  1.688E-10  3.780E-11  2.497E-13
  1.3000E+04  4.677E-05  2.461E-10  5.912E-11  3.906E-13
  1.4000E+04  6.318E-05  3.327E-10  8.520E-11  5.630E-13
  1.5000E+04  8.043E-05  4.238E-10  1.151E-10  7.608E-13
  1.6000E+04  9.768E-05  5.149E-10  1.477E-10  9.764E-13
  1.7000E+04  1.143E-04  6.025E-10  1.818E-10  1.202E-12
  1.8000E+04  1.296E-04  6.838E-10  2.164E-10  1.430E-12
  1.9000E+04  1.436E-04  7.573E-10  2.504E-10  1.656E-12
  2.0000E+04  1.558E-04  8.222E-10  2.834E-10  1.874E-12
  2.1000E+04  1.664E-04  8.783E-10  3.148E-10  2.082E-12
  2.2000E+04  1.755E-04  9.260E-10  3.443E-10  2.277E-12
  2.3000E+04  1.830E-04  9.661E-10  3.719E-10  2.460E-12
  2.4000E+04  1.893E-04  9.992E-10  3.975E-10  2.629E-12
  2.5000E+04  1.944E-04  1.026E-09  4.212E-10  2.786E-12
  2.6000E+04  1.985E-04  1.048E-09  4.431E-10  2.931E-12
  2.7000E+04  2.019E-04  1.066E-09  4.635E-10  3.066E-12
  2.8000E+04  2.045E-04  1.080E-09  4.823E-10  3.191E-12
  2.9000E+04  2.066E-04  1.091E-09  4.999E-10  3.307E-12
 Maximum Concentration and Time for Member #1:  1.091E-09  2.900E+04
 Maximum Concentration and Time for Member #2:  4.999E-10  2.900E+04
 Maximum Concentration and Time for Member #3:  3.307E-12  2.900E+04
 -----------------------------------------------------------------------------
 Contaminant Data
 -----------------------------------------------------------------------------
  Contaminant Name:               U-238
  Number of Progeny:              4
  Progeny Names:                 U-234       Th-230       Ra-226       Pb-210
  Half Life (y):                  4.470E+09 2.440E+05 7.700E+04 1.600E+03 2.230E+01
  Other Source Loss Rate (1/y):   0.000E+00
  Kd Source (ml/g):               6.000E-01
  Solubility Limit (mg/L):        1.000E+00
  Molecular Weight (mg/L):        2.380E+02
  Initial mass/activity:          2.228E+04
  Kd Unsat (ml/g):                6.000E-01
  Kd Aquifer (ml/g):              6.000E-01 6.000E-01 4.000E+01 8.000E+00 2.000E+03
  Risk/Dose Conversion Factor:    2.690E+05 2.830E+05 5.480E+05 1.330E+06 7.270E+06
 -----------------------------------------------------------------------------
 Calculated Contaminant Values
 -----------------------------------------------------------------------------
 Decay Constants (1/y):                  1.5507E-10 2.8408E-06 9.0019E-06 4.3322E-04
3.1083E-02
 Leach Rate Constant (1/y):              5.9709E-05
 Initial Pore Water Conc (Ci or mg/m**3):  1.3446E-02
 Solubility Limited Mass (mg):           1.6570E+09
 Solubility Limited Act (Ci):            5.5728E-01
 Solubility Limited Time (y):            6.3704E+08
 Unsaturated Retardation Factor:         2.2007E+01
 Mean Unsaturated Transit Time (y):      1.6554E+04
 Leading Edge Arrival Time (y):          2.5037E+03
 Aquifer Retardation Factor:             1.060E+01 1.060E+01 6.410E+02 1.290E+02
3.200E+04
 -----------------------------------------------------------------------------
 Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
 -----------------------------------------------------------------------------
    Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3 Conc Mbr 4 Conc Mbr 5
  (years)  (mg or Ci/y) (mg or Ci per cubic meter)
 -----------------------------------------------------------------------------
  2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
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3.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.0000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.1000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.3500E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.5000E+03	5.299E-27	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.6500E+03	9.769E-25	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.8000E+03	7.246E-23	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.9500E+03	2.763E-21	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.1000E+03	6.248E-20	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.2500E+03	9.298E-19	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.4000E+03	9.847E-18	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.5500E+03	7.881E-17	3.636E-22	2.624E-24	4.949E-28	7.034E-28	2.739E-30
2.7000E+03	4.993E-16	2.337E-21	1.786E-23	3.565E-27	5.292E-27	2.065E-29
2.8500E+03	2.599E-15	1.232E-20	9.930E-23	2.091E-26	3.234E-26	1.264E-28
3.2000E+03	6.628E-14	3.212E-19	2.907E-21	6.867E-25	1.156E-24	4.534E-27
3.4000E+03	3.111E-13	1.522E-18	1.463E-20	3.672E-24	6.452E-24	2.536E-26
3.6000E+03	1.225E-12	6.044E-18	6.150E-20	1.633E-23	2.987E-23	1.175E-25
3.8000E+03	4.160E-12	2.067E-17	2.220E-19	6.218E-23	1.180E-22	4.652E-25
4.0000E+03	1.246E-11	6.229E-17	7.038E-19	2.074E-22	4.075E-22	1.608E-24
4.2000E+03	3.350E-11	1.684E-16	1.997E-18	6.177E-22	1.253E-21	4.951E-24
4.4000E+03	8.206E-11	4.143E-16	5.146E-18	1.667E-21	3.485E-21	1.378E-23
4.6000E+03	1.854E-10	9.396E-16	1.220E-17	4.129E-21	8.879E-21	3.515E-23
4.8000E+03	3.901E-10	1.984E-15	2.687E-17	9.485E-21	2.095E-20	8.299E-23
5.0000E+03	7.712E-10	3.935E-15	5.549E-17	2.039E-20	4.618E-20	1.831E-22
5.2000E+03	1.443E-09	7.380E-15	1.082E-16	4.134E-20	9.585E-20	3.803E-22
5.4000E+03	2.569E-09	1.318E-14	2.006E-16	7.953E-20	1.885E-19	7.486E-22
5.6000E+03	4.379E-09	2.251E-14	3.553E-16	1.460E-19	3.535E-19	1.404E-21
5.8000E+03	7.177E-09	3.696E-14	6.040E-16	2.570E-19	6.347E-19	2.523E-21
6.2500E+03	1.926E-08	9.956E-14	1.752E-15	8.023E-19	2.066E-18	8.219E-21
6.5000E+03	3.126E-08	1.619E-13	2.962E-15	1.410E-18	3.706E-18	1.476E-20
6.7500E+03	4.879E-08	2.530E-13	4.805E-15	2.374E-18	6.366E-18	2.536E-20
7.0000E+03	7.351E-08	3.818E-13	7.516E-15	3.848E-18	1.051E-17	4.191E-20
7.2500E+03	1.073E-07	5.581E-13	1.138E-14	6.028E-18	1.677E-17	6.685E-20
7.5000E+03	1.523E-07	7.930E-13	1.672E-14	9.157E-18	2.590E-17	1.033E-19
7.7500E+03	2.107E-07	1.098E-12	2.391E-14	1.353E-17	3.887E-17	1.551E-19
8.0000E+03	2.849E-07	1.486E-12	3.339E-14	1.948E-17	5.684E-17	2.269E-19
8.2500E+03	3.770E-07	1.968E-12	4.560E-14	2.742E-17	8.115E-17	3.240E-19
8.5000E+03	4.896E-07	2.558E-12	6.103E-14	3.779E-17	1.134E-16	4.528E-19
8.7500E+03	6.247E-07	3.266E-12	8.019E-14	5.109E-17	1.552E-16	6.203E-19
9.0000E+03	7.844E-07	4.104E-12	1.036E-13	6.784E-17	2.087E-16	8.342E-19
9.2500E+03	9.706E-07	5.081E-12	1.318E-13	8.864E-17	2.759E-16	1.103E-18
9.5000E+03	1.185E-06	6.205E-12	1.652E-13	1.141E-16	3.591E-16	1.436E-18
9.7500E+03	1.428E-06	7.484E-12	2.045E-13	1.448E-16	4.607E-16	1.843E-18
1.0000E+04	1.702E-06	8.923E-12	2.499E-13	1.814E-16	5.832E-16	2.333E-18
1.0250E+04	2.007E-06	1.053E-11	3.021E-13	2.246E-16	7.292E-16	2.918E-18
1.1000E+04	3.108E-06	1.632E-11	5.021E-13	3.999E-16	1.334E-15	5.341E-18
1.2000E+04	4.992E-06	2.624E-11	8.796E-13	7.623E-16	2.625E-15	1.052E-17
1.3000E+04	7.273E-06	3.827E-11	1.388E-12	1.300E-15	4.598E-15	1.843E-17
1.4000E+04	9.825E-06	5.173E-11	2.017E-12	2.029E-15	7.352E-15	2.948E-17
1.5000E+04	1.251E-05	6.590E-11	2.749E-12	2.956E-15	1.093E-14	4.386E-17
1.6000E+04	1.519E-05	8.007E-11	3.558E-12	4.071E-15	1.533E-14	6.153E-17
1.7000E+04	1.777E-05	9.369E-11	4.417E-12	5.356E-15	2.050E-14	8.231E-17
1.8000E+04	2.016E-05	1.063E-10	5.301E-12	6.789E-15	2.637E-14	1.059E-16
1.9000E+04	2.232E-05	1.178E-10	6.188E-12	8.345E-15	3.284E-14	1.319E-16
2.0000E+04	2.423E-05	1.279E-10	7.062E-12	1.000E-14	3.982E-14	1.600E-16
2.1000E+04	2.588E-05	1.366E-10	7.910E-12	1.173E-14	4.722E-14	1.897E-16
2.2000E+04	2.728E-05	1.440E-10	8.725E-12	1.352E-14	5.497E-14	2.209E-16
2.3000E+04	2.846E-05	1.502E-10	9.502E-12	1.536E-14	6.299E-14	2.532E-16
2.4000E+04	2.943E-05	1.554E-10	1.024E-11	1.723E-14	7.125E-14	2.864E-16
2.5000E+04	3.023E-05	1.596E-10	1.094E-11	1.913E-14	7.971E-14	3.204E-16
2.6000E+04	3.088E-05	1.630E-10	1.161E-11	2.105E-14	8.833E-14	3.552E-16
2.7000E+04	3.139E-05	1.658E-10	1.224E-11	2.300E-14	9.712E-14	3.905E-16
2.8000E+04	3.181E-05	1.679E-10	1.284E-11	2.496E-14	1.061E-13	4.265E-16

```
  2.9000E+04  3.214E-05  1.697E-10  1.342E-11  2.695E-14  1.152E-13  4.631E-16
 Maximum Concentration and Time for Member #1:  1.697E-10  2.900E+04
 Maximum Concentration and Time for Member #2:  1.342E-11  2.900E+04
 Maximum Concentration and Time for Member #3:  2.695E-14  2.900E+04
 Maximum Concentration and Time for Member #4:  1.152E-13  2.900E+04
 Maximum Concentration and Time for Member #5:  4.631E-16  2.900E+04
 Execution Time (Seconds):   73
```

Proposed Cover Input File

```
Washington State PA Proposed Cover 0.002 m/y and no shadow            (Card 1)
1 1 0 2 1                             (Card 2) imode,itype,idisp,kflag idil
1 2 2 1 1                             (Card 3) imodel,isolve,isolveu,imoist,imoistu
$ I have fixed the moisture content to reflect the published values
6 12 0.001                            (Card 4) jstart jmax eps
70. 2.555E+04 2.0  365.  1.  0.025    (Card 5) bw,at,wi,ef,ed,dlim
0.  0.                                (Card 6) x0,y0
518.  382.  0.002                      (Card 7) l,w,perc
10.6 1.26                             (Card 8b) thicks,rhos
0.037                                 (Card 8c) thetas
$ 7.51  2.298 1710. 0.2724 0.0321       (Card 8d) alpha n ksat pors thetar
32.9  1.6  1.6                         (Card 9) depth,rhou,axu
$ The depth has been adjusted so the VZWTT is the same as background
$ infiltration (0.005 m/y)
$7.51  2.298 1710. 0.2724 0.0321       (Card 9b) alpha n ksat pors thetar
0.0457                                 (Card 9c) thetau
27.5  5.  5.0e-1   15.  15.           (Card 10) ax,ay,az,b,z
32.9  0.1  1.6                        (Card 11) u,phi,rhoa
1                                     (Card 12a nrecept
275.  0.                              (Card 12b) xrec(i) yrec(i)
6                                     (Card 13a)
200.  600.  50.                      (Card 13b)
700.  1200. 100.
1350. 3000. 150.
3200. 6000. 200.
6250. 10500. 250.
11000.  30000. 1000.
5                                     (Card 14) ncontam
$ I-129
0  0.3 0.3  129.  6.012  0.0 1.0e6 0.0 (Card 14a) nprog kds kdu zmw q0 rmi sl other
I-129 1.57E7 0.3 2.76e5                (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ Tc-99
0   0.0  0.0  99. 67.1   0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Tc-99 2.10E5 0.0 1460.                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ CL-36
0   0.0  0.0  36. 4.907  0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Cl-36 3.01E5 0.0 3030                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-235
2   0.6 0.6 235. 1.468E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-235  7.04E8 0.6 2.67e5                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pa-231 3.28E4 0.6 1.06e3                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ac-227 2.17E1 100. 1.48e3                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-238
4   0.6 0.6 238. 2.228E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-238  4.47E9 0.6 2.69e5                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
U-234  2.44E5 0.6 2.83e5                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Th-230 7.70E4 40. 5.48e5                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ra-226 1.60E3 8.  1.33e6                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pb-210 2.23E1 2000. 7.27e6                 (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
```

Proposed Cover Output File

```
 TIME OF RUN: 16:22:11.31  DATE OF RUN: 03/02/00
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                    GWSCREEN                     *
```

```
 *                  Version 2.5a                *
 *    A semi-analytical model for the assessment   *
 *    of the groundwater pathway from the leaching *
 *    of surficial and buried contamination and    *
 *  release of contaminants from percolation ponds *
 *                  01/04/2000                     *
 *                 Arthur S. Rood                  *
 *         Idaho National Engineering and          *
 *            Environmental Laboratory             *
 *                  PO Box 1625                    *
 *             Idaho Falls, Idaho 83415            *
 ***************************************************
============================================================================
         ACKNOWLEDGEMENT OF GOVERNMENT SPONSORSHIP AND
                  LIMITATION OF LIABILITY

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DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
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Cambridge University Press.
===========================================================================

OUTPUT FILE NAME: pcover.out
INPUT FILE NAME: pcover.par
Title: Washington State PA Proposed Cover 0.002 m/y and no shadow            (Card 1)
-----------------------------------------------------------------------------
Model Run Options
-----------------------------------------------------------------------------
IMODE Contaminant Type and Impacts:                         1
ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                 1
IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:       0
KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:        2
IDIL (1) No dilution factor (2) Include Dilution Factor:    1
IMOIST Source Moisture Content Option:                      1
IMOISTU Unsaturated Moisture Content Option:                1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:        1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)  2
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  2
JSTART:   6
JMAX  :  12
EPS   :  1.000E-03
Health Effects: Committed effective dose equivalent calculation
Output mass/activity units:   Ci
Output concentration units:   Ci/m**3
Dose/Risk Conversion Units:   rem/Ci
Output health effects units:  rem
-----------------------------------------------------------------------------
Exposure Parameters
-----------------------------------------------------------------------------
Body Mass (kg):             70.       Averaging Time (days):      25550.
Water Ingestion (L/d):      2.000E+00 Exposure Freq (day/year):   3.650E+02
Exposure Duration (y):      1.000E+00 Limiting Dose:              2.500E-02
-----------------------------------------------------------------------------
Site Parameters
-----------------------------------------------------------------------------
X Coordinate:               0.000E+00  Y Coordinate:               0.000E+00
Source Length (m):          5.180E+02  Source Width (m):           3.820E+02
Percolation Rate (m/y):     2.000E-03
Source Thickness (m):       1.060E+01  Src Bulk Density (g/cc):    1.260E+00
Source Moisture Content:    3.700E-02
```

```
-----------------------------------------------------------------------------
Unsaturated Zone Parameters
-----------------------------------------------------------------------------
Unsat Zone Thickness (m):    3.290E+01  Unsat Bulk Density:         1.600E+00
Unsat Dispersivity (m):      1.600E+00  Unsat Moisture Content:     4.570E-02
-----------------------------------------------------------------------------
Aquifer Zone Parameters
-----------------------------------------------------------------------------
Longitudinal Disp (m):       2.750E+01  Transverse Disp (m):        5.000E+00
Aquifer Thickness (m):       1.500E+01  Well Screen Thickness (m):  1.500E+01
Darcy Velocity (m/y):        3.290E+01  Aquifer Porosity:           1.000E-01
Bulk Density (g/cc):         1.600E+00
-----------------------------------------------------------------------------
Calculated Flow Parameters
-----------------------------------------------------------------------------
Percolation Water Flux (m3/y):  3.9575E+02
Unsat Pore Velocity (m/y):      4.3764E-02
Aquifer Pore Velocity (m/y):    3.2900E+02
Longitudinal Disp (m**2/y):     9.0475E+03
Transverse Disp (m**2/y):       1.6450E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                I-129
 Number of Progeny:               0
 Half Life (y):                   1.570E+07
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                3.000E-01
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         1.290E+02
 Initial mass/activity:           6.012E+00
 Kd Unsat (ml/g):                 3.000E-01
 Kd Aquifer (ml/g):               3.000E-01
 Risk/Dose Conversion Factor:     2.760E+05
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    4.4150E-08
Leach Rate Constant (1/y):                4.5465E-04
Initial Pore Water Conc (Ci or mg/m**3):  6.9067E-06
Solubility Limited Mass (mg):             8.7046E+14
Solubility Limited Act (Ci):              1.5378E+08
Unsaturated Retardation Factor:           1.1503E+01
Mean Unsaturated Transit Time (y):        8.6478E+03
Leading Edge Arrival Time (y):            1.3073E+03
Aquifer Retardation Factor:               5.800E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00
 8.0000E+02  1.476E-24  0.000E+00
 9.0000E+02  7.248E-22  0.000E+00
 1.0000E+03  1.015E-19  0.000E+00
 1.1000E+03  5.764E-18  0.000E+00
 1.3500E+03  1.002E-14  4.613E-20
 1.5000E+03  2.638E-13  1.246E-18
 1.6500E+03  3.795E-12  1.828E-17
 1.8000E+03  3.470E-11  1.696E-16
 1.9500E+03  2.238E-10  1.107E-15
```

```
 2.1000E+03  1.097E-09  5.474E-15
 2.2500E+03  4.314E-09  2.169E-14
 2.4000E+03  1.419E-08  7.182E-14
 2.5500E+03  4.030E-08  2.049E-13
 2.7000E+03  1.012E-07  5.168E-13
 2.8500E+03  2.291E-07  1.174E-12
 3.2000E+03  1.118E-06  5.767E-12
 3.4000E+03  2.354E-06  1.218E-11
 3.6000E+03  4.520E-06  2.345E-11
 3.8000E+03  8.026E-06  4.173E-11
 4.0000E+03  1.333E-05  6.945E-11
 4.2000E+03  2.092E-05  1.091E-10
 4.4000E+03  3.126E-05  1.633E-10
 4.6000E+03  4.472E-05  2.339E-10
 4.8000E+03  6.163E-05  3.226E-10
 5.0000E+03  8.215E-05  4.304E-10
 5.2000E+03  1.063E-04  5.576E-10
 5.4000E+03  1.341E-04  7.036E-10
 5.6000E+03  1.652E-04  8.673E-10
 5.8000E+03  1.993E-04  1.047E-09
 6.2500E+03  2.844E-04  1.496E-09
 6.5000E+03  3.348E-04  1.762E-09
 6.7500E+03  3.860E-04  2.032E-09
 7.0000E+03  4.367E-04  2.300E-09
 7.2500E+03  4.857E-04  2.559E-09
 7.5000E+03  5.321E-04  2.804E-09
 7.7500E+03  5.749E-04  3.031E-09
 8.0000E+03  6.135E-04  3.235E-09
 8.2500E+03  6.472E-04  3.414E-09
 8.5000E+03  6.757E-04  3.565E-09
 8.7500E+03  6.988E-04  3.688E-09
 9.0000E+03  7.164E-04  3.781E-09
 9.2500E+03  7.286E-04  3.846E-09
 9.5000E+03  7.355E-04  3.884E-09
 9.7500E+03  7.375E-04  3.894E-09
 1.0000E+04  7.347E-04  3.880E-09
 1.0250E+04  7.277E-04  3.844E-09
 1.1000E+04  6.853E-04  3.621E-09
 1.2000E+04  5.953E-04  3.147E-09
 1.3000E+04  4.895E-04  2.588E-09
 1.4000E+04  3.855E-04  2.039E-09
 1.5000E+04  2.933E-04  1.552E-09
 1.6000E+04  2.171E-04  1.148E-09
 1.7000E+04  1.570E-04  8.308E-10
 1.8000E+04  1.114E-04  5.897E-10
 1.9000E+04  7.786E-05  4.120E-10
 2.0000E+04  5.368E-05  2.841E-10
 2.1000E+04  3.660E-05  1.937E-10
 2.2000E+04  2.471E-05  1.308E-10
 2.3000E+04  1.655E-05  8.761E-11
 2.4000E+04  1.101E-05  5.827E-11
 2.5000E+04  7.277E-06  3.852E-11
 2.6000E+04  4.786E-06  2.533E-11
 2.7000E+04  3.133E-06  1.659E-11
 2.8000E+04  2.043E-06  1.082E-11
 2.9000E+04  1.328E-06  7.028E-12
Maximum Concentration and Time for Member #1:  3.894E-09  9.750E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:              Tc-99
 Number of Progeny:             0
 Half Life (y):                 2.100E+05
 Other Source Loss Rate (1/y):  0.000E+00
 Kd Source (ml/g):              0.000E+00
 Solubility Limit (mg/L):       1.000E+06
 Molecular Weight (mg/L):       9.900E+01
 Initial mass/activity:         6.710E+01
 Kd Unsat (ml/g):               0.000E+00
 Kd Aquifer (ml/g):             0.000E+00
```

```
 Risk/Dose Conversion Factor:    1.460E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                     3.3007E-06
Leach Rate Constant (1/y):                 5.0994E-03
Initial Pore Water Conc (Ci or mg/m**3):  8.6461E-04
Solubility Limited Mass (mg):              7.7607E+13
Solubility Limited Act (Ci):               1.3356E+09
Unsaturated Retardation Factor:            1.0000E+00
Mean Unsaturated Transit Time (y):         7.5176E+02
Leading Edge Arrival Time (y):             1.1365E+02
Aquifer Retardation Factor:                1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  8.228E-07  3.963E-12
 2.5000E+02  3.274E-05  1.632E-10
 3.0000E+02  3.515E-04  1.786E-09
 3.5000E+02  1.780E-03  9.151E-09
 4.0000E+02  5.630E-03  2.916E-08
 4.5000E+02  1.299E-02  6.761E-08
 5.0000E+02  2.401E-02  1.255E-07
 5.5000E+02  3.776E-02  1.979E-07
 7.0000E+02  7.856E-02  4.137E-07
 8.0000E+02  9.224E-02  4.867E-07
 9.0000E+02  9.218E-02  4.871E-07
 1.0000E+03  8.228E-02  4.352E-07
 1.1000E+03  6.765E-02  3.580E-07
 1.3500E+03  3.264E-02  1.729E-07
 1.5000E+03  1.891E-02  1.002E-07
 1.6500E+03  1.039E-02  5.509E-08
 1.8000E+03  5.489E-03  2.911E-08
 1.9500E+03  2.817E-03  1.494E-08
 2.1000E+03  1.414E-03  7.502E-09
 2.2500E+03  6.979E-04  3.703E-09
 2.4000E+03  3.400E-04  1.804E-09
 2.5500E+03  1.639E-04  8.700E-10
 2.7000E+03  7.844E-05  4.163E-10
 2.8500E+03  3.730E-05  1.979E-10
 3.2000E+03  6.472E-06  3.435E-11
 3.4000E+03  2.362E-06  1.253E-11
 3.6000E+03  8.588E-07  4.558E-12
 3.8000E+03  3.115E-07  1.653E-12
 4.0000E+03  1.128E-07  5.986E-13
 4.2000E+03  4.078E-08  2.164E-13
 4.4000E+03  1.473E-08  7.818E-14
 4.6000E+03  5.318E-09  2.822E-14
 4.8000E+03  1.919E-09  1.018E-14
 5.0000E+03  6.921E-10  3.673E-15
 5.2000E+03  2.496E-10  1.325E-15
 5.4000E+03  8.998E-11  4.776E-16
 5.6000E+03  3.244E-11  1.722E-16
 5.8000E+03  1.169E-11  6.207E-17
 6.2500E+03  1.177E-12  6.248E-18
 6.5000E+03  3.287E-13  1.745E-18
 6.7500E+03  9.180E-14  4.872E-19
 7.0000E+03  2.563E-14  1.361E-19
 7.2500E+03  7.159E-15  3.800E-20
 7.5000E+03  1.999E-15  1.061E-20
 7.7500E+03  5.582E-16  2.963E-21
 8.0000E+03  1.559E-16  8.273E-22
 8.2500E+03  4.353E-17  2.310E-22
 8.5000E+03  1.215E-17  6.451E-23
 8.7500E+03  3.394E-18  1.801E-23
 9.0000E+03  9.477E-19  5.030E-24
 9.2500E+03  2.646E-19  1.405E-24
```

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 9.5000E+03  7.390E-20  3.922E-25
 9.7500E+03  2.064E-20  1.095E-25
 1.0000E+04  5.762E-21  3.058E-26
 1.0250E+04  1.609E-21  8.540E-27
 1.1000E+04  3.503E-23  1.860E-28
 1.2000E+04  2.130E-25  1.131E-30
 1.3000E+04  1.295E-27  6.874E-33
 1.4000E+04  7.874E-30  4.180E-35
 1.5000E+04  4.788E-32  2.541E-37
 1.6000E+04  2.911E-34  1.545E-39
 1.7000E+04  1.770E-36  9.394E-42
 1.8000E+04  1.076E-38  5.712E-44
 1.9000E+04  6.543E-41  3.473E-46
 2.0000E+04  3.978E-43  2.111E-48
 2.1000E+04  2.419E-45  1.284E-50
 2.2000E+04  1.471E-47  7.805E-53
 2.3000E+04  8.941E-50  4.746E-55
 2.4000E+04  5.436E-52  2.885E-57
 2.5000E+04  3.305E-54  1.754E-59
 2.6000E+04  2.010E-56  1.067E-61
 2.7000E+04  1.222E-58  6.485E-64
 2.8000E+04  7.429E-61  3.943E-66
 2.9000E+04  4.517E-63  2.397E-68
Maximum Concentration and Time for Member #1:  4.871E-07  9.000E+02
------------------------------------------------------------------------------
Contaminant Data
------------------------------------------------------------------------------
 Contaminant Name:               Cl-36
 Number of Progeny:              0
 Half Life (y):                  3.010E+05
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):               0.000E+00
 Solubility Limit (mg/L):        1.000E+06
 Molecular Weight (mg/L):        3.600E+01
 Initial mass/activity:          4.907E+00
 Kd Unsat (ml/g):                0.000E+00
 Kd Aquifer (ml/g):              0.000E+00
 Risk/Dose Conversion Factor:    3.030E+03
------------------------------------------------------------------------------
Calculated Contaminant Values
------------------------------------------------------------------------------
Decay Constants (1/y):                    2.3028E-06
Leach Rate Constant (1/y):                5.0994E-03
Initial Pore Water Conc (Ci or mg/m**3):  6.3229E-05
Solubility Limited Mass (mg):             7.7607E+13
Solubility Limited Act (Ci):              2.5625E+09
Unsaturated Retardation Factor:           1.0000E+00
Mean Unsaturated Transit Time (y):        7.5176E+02
Leading Edge Arrival Time (y):            1.1365E+02
Aquifer Retardation Factor:               1.000E+00
------------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
------------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
------------------------------------------------------------------------------
 2.0000E+02  6.018E-08  2.899E-13
 2.5000E+02  2.395E-06  1.194E-11
 3.0000E+02  2.571E-05  1.306E-10
 3.5000E+02  1.302E-04  6.695E-10
 4.0000E+02  4.119E-04  2.133E-09
 4.5000E+02  9.502E-04  4.947E-09
 5.0000E+02  1.757E-03  9.180E-09
 5.5000E+02  2.763E-03  1.448E-08
 7.0000E+02  5.749E-03  3.028E-08
 8.0000E+02  6.751E-03  3.562E-08
 9.0000E+02  6.747E-03  3.565E-08
 1.0000E+03  6.023E-03  3.186E-08
 1.1000E+03  4.952E-03  2.621E-08
 1.3500E+03  2.390E-03  1.266E-08
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 1.5000E+03  1.385E-03  7.342E-09
 1.6500E+03  7.610E-04  4.035E-09
 1.8000E+03  4.021E-04  2.133E-09
 1.9500E+03  2.064E-04  1.095E-09
 2.1000E+03  1.036E-04  5.497E-10
 2.2500E+03  5.115E-05  2.714E-10
 2.4000E+03  2.492E-05  1.322E-10
 2.5500E+03  1.202E-05  6.378E-11
 2.7000E+03  5.752E-06  3.052E-11
 2.8500E+03  2.735E-06  1.452E-11
 3.2000E+03  4.748E-07  2.520E-12
 3.4000E+03  1.733E-07  9.198E-13
 3.6000E+03  6.303E-08  3.345E-13
 3.8000E+03  2.287E-08  1.214E-13
 4.0000E+03  8.280E-09  4.395E-14
 4.2000E+03  2.995E-09  1.589E-14
 4.4000E+03  1.082E-09  5.743E-15
 4.6000E+03  3.907E-10  2.074E-15
 4.8000E+03  1.410E-10  7.483E-16
 5.0000E+03  5.087E-11  2.700E-16
 5.2000E+03  1.835E-11  9.738E-17
 5.4000E+03  6.616E-12  3.512E-17
 5.6000E+03  2.386E-12  1.266E-17
 5.8000E+03  8.601E-13  4.565E-18
 6.2500E+03  8.662E-14  4.598E-19
 6.5000E+03  2.420E-14  1.284E-19
 6.7500E+03  6.759E-15  3.587E-20
 7.0000E+03  1.888E-15  1.002E-20
 7.2500E+03  5.273E-16  2.799E-21
 7.5000E+03  1.473E-16  7.817E-22
 7.7500E+03  4.114E-17  2.183E-22
 8.0000E+03  1.149E-17  6.099E-23
 8.2500E+03  3.209E-18  1.703E-23
 8.5000E+03  8.964E-19  4.758E-24
 8.7500E+03  2.504E-19  1.329E-24
 9.0000E+03  6.993E-20  3.712E-25
 9.2500E+03  1.953E-20  1.037E-25
 9.5000E+03  5.456E-21  2.896E-26
 9.7500E+03  1.524E-21  8.088E-27
 1.0000E+04  4.256E-22  2.259E-27
 1.0250E+04  1.189E-22  6.310E-28
 1.1000E+04  2.590E-24  1.375E-29
 1.2000E+04  1.577E-26  8.368E-32
 1.3000E+04  9.595E-29  5.093E-34
 1.4000E+04  5.840E-31  3.099E-36
 1.5000E+04  3.554E-33  1.886E-38
 1.6000E+04  2.163E-35  1.148E-40
 1.7000E+04  1.316E-37  6.987E-43
 1.8000E+04  8.012E-40  4.253E-45
 1.9000E+04  4.876E-42  2.588E-47
 2.0000E+04  2.968E-44  1.575E-49
 2.1000E+04  1.806E-46  9.587E-52
 2.2000E+04  1.099E-48  5.835E-54
 2.3000E+04  6.690E-51  3.551E-56
 2.4000E+04  4.072E-53  2.161E-58
 2.5000E+04  2.478E-55  1.315E-60
 2.6000E+04  1.508E-57  8.005E-63
 2.7000E+04  9.180E-60  4.872E-65
 2.8000E+04  5.587E-62  2.965E-67
 2.9000E+04  3.400E-64  1.805E-69
Maximum Concentration and Time for Member #1:  3.565E-08  9.000E+02
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:              U-235
 Number of Progeny:             2
 Progeny Names:                Pa-231      Ac-227
 Half Life (y):                 7.040E+08 3.280E+04 2.170E+01
 Other Source Loss Rate (1/y):  0.000E+00
 Kd Source (ml/g):              6.000E-01
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 Solubility Limit (mg/L):        1.000E+00
 Molecular Weight (mg/L):        2.350E+02
 Initial mass/activity:          1.468E+04
 Kd Unsat (ml/g):                6.000E-01
 Kd Aquifer (ml/g):              6.000E-01 6.000E-01 1.000E+02
 Risk/Dose Conversion Factor:    2.670E+05 1.060E+03 1.480E+03
------------------------------------------------------------------------------
Calculated Contaminant Values
------------------------------------------------------------------------------
Decay Constants (1/y):                   9.8458E-10 2.1133E-05 3.1942E-02
Leach Rate Constant (1/y):               2.3793E-04
Initial Pore Water Conc (Ci or mg/m**3): 8.8258E-03
Solubility Limited Mass (mg):            1.6633E+09
Solubility Limited Act (Ci):             3.5972E+00
Solubility Limited Time (y):             1.7005E+07
Unsaturated Retardation Factor:          2.2007E+01
Mean Unsaturated Transit Time (y):       1.6544E+04
Leading Edge Arrival Time (y):           2.5010E+03
Aquifer Retardation Factor:              1.060E+01 1.060E+01 1.601E+03
------------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
------------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
------------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 8.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 9.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.0000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.1000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.3500E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.5000E+03  1.456E-25  0.000E+00  0.000E+00  0.000E+00
 1.6500E+03  2.660E-23  0.000E+00  0.000E+00  0.000E+00
 1.8000E+03  1.963E-21  0.000E+00  0.000E+00  0.000E+00
 1.9500E+03  7.453E-20  0.000E+00  0.000E+00  0.000E+00
 2.1000E+03  1.679E-18  0.000E+00  0.000E+00  0.000E+00
 2.2500E+03  2.490E-17  0.000E+00  0.000E+00  0.000E+00
 2.4000E+03  2.630E-16  0.000E+00  0.000E+00  0.000E+00
 2.5500E+03  2.099E-15  9.687E-21  5.082E-22  3.325E-24
 2.7000E+03  1.327E-14  6.213E-20  3.446E-21  2.256E-23
 2.8500E+03  6.893E-14  3.267E-19  1.910E-20  1.251E-22
 3.2000E+03  1.751E-12  8.487E-18  5.550E-19  3.640E-21
 3.4000E+03  8.203E-12  4.015E-17  2.784E-18  1.827E-20
 3.6000E+03  3.224E-11  1.591E-16  1.166E-17  7.654E-20
 3.8000E+03  1.093E-10  5.435E-16  4.194E-17  2.755E-19
 4.0000E+03  3.270E-10  1.635E-15  1.326E-16  8.710E-19
 4.2000E+03  8.783E-10  4.415E-15  3.749E-16  2.465E-18
 4.4000E+03  2.149E-09  1.085E-14  9.635E-16  6.336E-18
 4.6000E+03  4.850E-09  2.458E-14  2.277E-15  1.498E-17
 4.8000E+03  1.020E-08  5.187E-14  5.003E-15  3.292E-17
 5.0000E+03  2.014E-08  1.028E-13  1.030E-14  6.782E-17
 5.2000E+03  3.765E-08  1.926E-13  2.004E-14  1.320E-16
 5.4000E+03  6.700E-08  3.436E-13  3.706E-14  2.440E-16
 5.6000E+03  1.141E-07  5.866E-13  6.547E-14  4.312E-16
 5.8000E+03  1.869E-07  9.626E-13  1.110E-13  7.315E-16
 6.2500E+03  5.010E-07  2.590E-12  3.204E-13  2.111E-15
 6.5000E+03  8.126E-07  4.208E-12  5.401E-13  3.560E-15
 6.7500E+03  1.267E-06  6.573E-12  8.738E-13  5.761E-15
 7.0000E+03  1.909E-06  9.913E-12  1.363E-12  8.987E-15
 7.2500E+03  2.785E-06  1.448E-11  2.057E-12  1.357E-14
 7.5000E+03  3.951E-06  2.057E-11  3.015E-12  1.989E-14
 7.7500E+03  5.464E-06  2.847E-11  4.302E-12  2.837E-14
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  8.0000E+03  7.383E-06  3.851E-11  5.990E-12  3.952E-14
  8.2500E+03  9.769E-06  5.100E-11  8.160E-12  5.384E-14
  8.5000E+03  1.268E-05  6.625E-11  1.089E-11  7.188E-14
  8.7500E+03  1.617E-05  8.457E-11  1.428E-11  9.422E-14
  9.0000E+03  2.030E-05  1.062E-10  1.840E-11  1.214E-13
  9.2500E+03  2.511E-05  1.315E-10  2.334E-11  1.541E-13
  9.5000E+03  3.065E-05  1.605E-10  2.920E-11  1.927E-13
  9.7500E+03  3.693E-05  1.936E-10  3.604E-11  2.379E-13
  1.0000E+04  4.400E-05  2.307E-10  4.395E-11  2.902E-13
  1.0250E+04  5.187E-05  2.721E-10  5.299E-11  3.499E-13
  1.1000E+04  8.028E-05  4.216E-10  8.744E-11  5.775E-13
  1.2000E+04  1.289E-04  6.775E-10  1.517E-10  1.002E-12
  1.3000E+04  1.876E-04  9.873E-10  2.372E-10  1.567E-12
  1.4000E+04  2.533E-04  1.334E-09  3.416E-10  2.258E-12
  1.5000E+04  3.224E-04  1.699E-09  4.614E-10  3.050E-12
  1.6000E+04  3.914E-04  2.063E-09  5.919E-10  3.912E-12
  1.7000E+04  4.577E-04  2.413E-09  7.283E-10  4.815E-12
  1.8000E+04  5.192E-04  2.739E-09  8.665E-10  5.729E-12
  1.9000E+04  5.748E-04  3.032E-09  1.003E-09  6.630E-12
  2.0000E+04  6.238E-04  3.291E-09  1.135E-09  7.502E-12
  2.1000E+04  6.662E-04  3.516E-09  1.260E-09  8.332E-12
  2.2000E+04  7.022E-04  3.706E-09  1.378E-09  9.114E-12
  2.3000E+04  7.324E-04  3.866E-09  1.488E-09  9.843E-12
  2.4000E+04  7.574E-04  3.998E-09  1.591E-09  1.052E-11
  2.5000E+04  7.778E-04  4.106E-09  1.685E-09  1.115E-11
  2.6000E+04  7.943E-04  4.194E-09  1.773E-09  1.173E-11
  2.7000E+04  8.077E-04  4.264E-09  1.854E-09  1.227E-11
  2.8000E+04  8.183E-04  4.320E-09  1.930E-09  1.277E-11
  2.9000E+04  8.267E-04  4.365E-09  2.000E-09  1.323E-11
 Maximum Concentration and Time for Member #1:  4.365E-09  2.900E+04
 Maximum Concentration and Time for Member #2:  2.000E-09  2.900E+04
 Maximum Concentration and Time for Member #3:  1.323E-11  2.900E+04
 -----------------------------------------------------------------------------
 Contaminant Data
 -----------------------------------------------------------------------------
  Contaminant Name:              U-238
  Number of Progeny:             4
  Progeny Names:                U-234       Th-230       Ra-226       Pb-210
  Half Life (y):                 4.470E+09 2.440E+05 7.700E+04 1.600E+03 2.230E+01
  Other Source Loss Rate (1/y):  0.000E+00
  Kd Source (ml/g):              6.000E-01
  Solubility Limit (mg/L):       1.000E+00
  Molecular Weight (mg/L):       2.380E+02
  Initial mass/activity:         2.228E+04
  Kd Unsat (ml/g):               6.000E-01
  Kd Aquifer (ml/g):             6.000E-01 6.000E-01 4.000E+01 8.000E+00 2.000E+03
  Risk/Dose Conversion Factor:   2.690E+05 2.830E+05 5.480E+05 1.330E+06 7.270E+06
 -----------------------------------------------------------------------------
 Calculated Contaminant Values
 -----------------------------------------------------------------------------
 Decay Constants (1/y):                  1.5507E-10 2.8408E-06 9.0019E-06 4.3322E-04
3.1083E-02
 Leach Rate Constant (1/y):              2.3793E-04
 Initial Pore Water Conc (Ci or mg/m**3):  1.3395E-02
 Solubility Limited Mass (mg):           1.6633E+09
 Solubility Limited Act (Ci):            5.5939E-01
 Solubility Limited Time (y):            1.6526E+08
 Unsaturated Retardation Factor:         2.2007E+01
 Mean Unsaturated Transit Time (y):      1.6544E+04
 Leading Edge Arrival Time (y):          2.5010E+03
 Aquifer Retardation Factor:             1.060E+01 1.060E+01 6.410E+02 1.290E+02
3.200E+04
 -----------------------------------------------------------------------------
 Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
 -----------------------------------------------------------------------------
    Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3 Conc Mbr 4 Conc Mbr 5
  (years)  (mg or Ci/y) (mg or Ci per cubic meter)
 -----------------------------------------------------------------------------
  2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
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3.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.0000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.1000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.3500E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.5000E+03	2.265E-26	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.6500E+03	4.137E-24	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.8000E+03	3.053E-22	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.9500E+03	1.159E-20	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.1000E+03	2.611E-19	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.2500E+03	3.872E-18	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.4000E+03	4.089E-17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.5500E+03	3.265E-16	1.506E-21	1.087E-23	2.050E-27	2.915E-27	1.135E-29
2.7000E+03	2.064E-15	9.662E-21	7.383E-23	1.474E-26	2.188E-26	8.536E-29
2.8500E+03	1.072E-14	5.081E-20	4.097E-22	8.628E-26	1.334E-25	5.215E-28
3.2000E+03	2.723E-13	1.320E-18	1.194E-20	2.822E-24	4.749E-24	1.863E-26
3.4000E+03	1.276E-12	6.244E-18	6.001E-20	1.506E-23	2.646E-23	1.040E-25
3.6000E+03	5.014E-12	2.475E-17	2.518E-19	6.686E-23	1.223E-22	4.813E-25
3.8000E+03	1.700E-11	8.452E-17	9.074E-19	2.542E-22	4.825E-22	1.902E-24
4.0000E+03	5.086E-11	2.543E-16	2.873E-18	8.469E-22	1.664E-21	6.565E-24
4.2000E+03	1.366E-10	6.865E-16	8.142E-18	2.519E-21	5.110E-21	2.019E-23
4.4000E+03	3.342E-10	1.687E-15	2.096E-17	6.789E-21	1.419E-20	5.613E-23
4.6000E+03	7.542E-10	3.823E-15	4.963E-17	1.680E-20	3.613E-20	1.430E-22
4.8000E+03	1.586E-09	8.066E-15	1.092E-16	3.856E-20	8.515E-20	3.373E-22
5.0000E+03	3.132E-09	1.598E-14	2.254E-16	8.283E-20	1.876E-19	7.436E-22
5.2000E+03	5.854E-09	2.995E-14	4.392E-16	1.678E-19	3.890E-19	1.543E-21
5.4000E+03	1.042E-08	5.344E-14	8.135E-16	3.225E-19	7.646E-19	3.036E-21
5.6000E+03	1.775E-08	9.122E-14	1.440E-15	5.917E-19	1.433E-18	5.691E-21
5.8000E+03	2.907E-08	1.497E-13	2.446E-15	1.041E-18	2.571E-18	1.022E-20
6.2500E+03	7.790E-08	4.027E-13	7.087E-15	3.245E-18	8.355E-18	3.325E-20
6.5000E+03	1.264E-07	6.544E-13	1.197E-14	5.698E-18	1.498E-17	5.965E-20
6.7500E+03	1.971E-07	1.022E-12	1.941E-14	9.590E-18	2.572E-17	1.025E-19
7.0000E+03	2.968E-07	1.542E-12	3.035E-14	1.554E-17	4.246E-17	1.692E-19
7.2500E+03	4.331E-07	2.252E-12	4.591E-14	2.433E-17	6.767E-17	2.698E-19
7.5000E+03	6.144E-07	3.199E-12	6.743E-14	3.694E-17	1.045E-16	4.167E-19
7.7500E+03	8.497E-07	4.428E-12	9.642E-14	5.455E-17	1.567E-16	6.255E-19
8.0000E+03	1.148E-06	5.989E-12	1.346E-13	7.853E-17	2.291E-16	9.145E-19
8.2500E+03	1.519E-06	7.931E-12	1.837E-13	1.105E-16	3.270E-16	1.306E-18
8.5000E+03	1.972E-06	1.030E-11	2.458E-13	1.522E-16	4.566E-16	1.824E-18
8.7500E+03	2.515E-06	1.315E-11	3.229E-13	2.057E-16	6.250E-16	2.497E-18
9.0000E+03	3.157E-06	1.652E-11	4.170E-13	2.731E-16	8.401E-16	3.358E-18
9.2500E+03	3.905E-06	2.044E-11	5.302E-13	3.567E-16	1.110E-15	4.439E-18
9.5000E+03	4.766E-06	2.496E-11	6.647E-13	4.589E-16	1.445E-15	5.777E-18
9.7500E+03	5.744E-06	3.010E-11	8.223E-13	5.823E-16	1.853E-15	7.411E-18
1.0000E+04	6.843E-06	3.588E-11	1.005E-12	7.294E-16	2.345E-15	9.381E-18
1.0250E+04	8.066E-06	4.231E-11	1.214E-12	9.028E-16	2.931E-15	1.173E-17
1.1000E+04	1.248E-05	6.556E-11	2.017E-12	1.606E-15	5.359E-15	2.146E-17
1.2000E+04	2.004E-05	1.054E-10	3.531E-12	3.060E-15	1.054E-14	4.221E-17
1.3000E+04	2.918E-05	1.535E-10	5.567E-12	5.213E-15	1.845E-14	7.394E-17
1.4000E+04	3.940E-05	2.075E-10	8.089E-12	8.138E-15	2.948E-14	1.182E-16
1.5000E+04	5.013E-05	2.641E-10	1.102E-11	1.185E-14	4.382E-14	1.758E-16
1.6000E+04	6.087E-05	3.208E-10	1.426E-11	1.631E-14	6.144E-14	2.466E-16
1.7000E+04	7.117E-05	3.753E-10	1.769E-11	2.146E-14	8.213E-14	3.297E-16
1.8000E+04	8.074E-05	4.259E-10	2.123E-11	2.719E-14	1.056E-13	4.241E-16
1.9000E+04	8.938E-05	4.715E-10	2.478E-11	3.341E-14	1.315E-13	5.281E-16
2.0000E+04	9.700E-05	5.119E-10	2.827E-11	4.003E-14	1.594E-13	6.404E-16
2.1000E+04	1.036E-04	5.467E-10	3.166E-11	4.696E-14	1.890E-13	7.594E-16
2.2000E+04	1.092E-04	5.764E-10	3.492E-11	5.412E-14	2.200E-13	8.840E-16
2.3000E+04	1.139E-04	6.012E-10	3.803E-11	6.147E-14	2.521E-13	1.013E-15
2.4000E+04	1.178E-04	6.218E-10	4.098E-11	6.895E-14	2.851E-13	1.146E-15
2.5000E+04	1.210E-04	6.386E-10	4.378E-11	7.654E-14	3.189E-13	1.282E-15
2.6000E+04	1.235E-04	6.522E-10	4.644E-11	8.423E-14	3.534E-13	1.421E-15
2.7000E+04	1.256E-04	6.632E-10	4.896E-11	9.200E-14	3.886E-13	1.562E-15

```
  2.8000E+04  1.272E-04  6.719E-10  5.137E-11  9.986E-14  4.243E-13  1.706E-15
  2.9000E+04  1.286E-04  6.788E-10  5.368E-11  1.078E-13  4.607E-13  1.853E-15
 Maximum Concentration and Time for Member #1:  6.788E-10  2.900E+04
 Maximum Concentration and Time for Member #2:  5.368E-11  2.900E+04
 Maximum Concentration and Time for Member #3:  1.078E-13  2.900E+04
 Maximum Concentration and Time for Member #4:  4.607E-13  2.900E+04
 Maximum Concentration and Time for Member #5:  1.853E-15  2.900E+04
 Execution Time (Seconds):   70
```

Background Cover Input File

```
Washington State PA Background Infiltration 0.005 m/y and no shadow           (Card 1)
1 1 0 2 1                             (Card 2) imode,itype,idisp,kflag idil
1 1 2 1 1                             (Card 3) imodel,isolve,isolveu,imoist,imoistu
$ I have fixed the moisture content to reflect the published values
6 13 0.001                            (Card 4) jstart jmax eps
70. 2.555E+04 2.0  365.  1.  0.025    (Card 5) bw,at,wi,ef,ed,dlim
0.  0.                                (Card 6) x0,y0
518.  382.  0.005                      (Card 7) l,w,perc
10.6 1.26                             (Card 8b) thicks,rhos
0.0457                                 (Card 8c) thetas
$ 7.51  2.298 1710. 0.2724 0.0321       (Card 8d) alpha n ksat pors thetar
82.3  1.6  4.                         (Card 9) depth,rhou,axu
$7.51  2.298 1710. 0.2724 0.0321       (Card 9b) alpha n ksat pors thetar
0.0457                                 (Card 9c) thetau
27.5  5.  5.0e-1   15.  15.           (Card 10) ax,ay,az,b,z
32.9  0.1  1.6                        (Card 11) u,phi,rhoa
1                                     (Card 12a nrecept
275.  0.                              (Card 12b) xrec(i) yrec(i)
5                                     (Card 13a)
200.  600.  50.                      (Card 13b)
700.  1200. 100.
1350. 3000. 150.
3200. 6000. 200.
6250. 10500. 250.
5                                     (Card 14) ncontam
$ I-129
0  0.3 0.3  129.  6.012  0.0 1.0e6 0.0 (Card 14a) nprog kds kdu zmw q0 rmi sl other
I-129 1.57E7 0.3 2.76e5                (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ Tc-99
0   0.0  0.0  99. 67.1   0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Tc-99 2.10E5 0.0 1460.                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ CL-36
0   0.0  0.0  36. 4.907  0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Cl-36 3.01E5 0.0 3030                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-235
2   0.6 0.6 235. 1.468E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-235  7.04E8 0.6 2.67e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pa-231 3.28E4 0.6 1.06e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ac-227 2.17E1 100. 1.48e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-238
4   0.6 0.6 238. 2.228E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-238  4.47E9 0.6 2.69e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
U-234  2.44E5 0.6 2.83e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Th-230 7.70E4 40. 5.48e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ra-226 1.60E3 8.  1.33e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pb-210 2.23E1 2000. 7.27e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
```

Background Cover Output File

```
 TIME OF RUN: 11:34:57.84  DATE OF RUN: 03/10/:0
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                    GWSCREEN                     *
   *                   Version 2.5a                  *
   *    A semi-analytical model for the assessment   *
   *    of the groundwater pathway from the leaching *
   *    of surficial and buried contamination and    *
```

```
 *  release of contaminants from percolation ponds *
 *                  01/04/2000                      *
 *                 Arthur S. Rood                   *
 *         Idaho National Engineering and           *
 *            Environmental Laboratory              *
 *                  PO Box 1625                     *
 *             Idaho Falls, Idaho 83415             *
 ***************************************************
============================================================================
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===========================================================================

OUTPUT FILE NAME: bkg.out
INPUT FILE NAME: bkg.par
Title: Washington State PA Background Infiltration 0.005 m/y and no shadow            (
-----------------------------------------------------------------------------
Model Run Options
-----------------------------------------------------------------------------
IMODE Contaminant Type and Impacts:                           1
ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                   1
IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:         0
KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:          2
IDIL (1) No dilution factor (2) Include Dilution Factor:      1
IMOIST Source Moisture Content Option:                        1
IMOISTU Unsaturated Moisture Content Option:                  1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:          1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)    1
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  2
JSTART:   6
JMAX  :  13
EPS   :  1.000E-03
Health Effects: Committed effective dose equivalent calculation
Output mass/activity units:   Ci
Output concentration units:   Ci/m**3
Dose/Risk Conversion Units:   rem/Ci
Output health effects units:  rem
-----------------------------------------------------------------------------
Exposure Parameters
-----------------------------------------------------------------------------
Body Mass (kg):              70.       Averaging Time (days):      25550.
Water Ingestion (L/d):       2.000E+00 Exposure Freq (day/year):   3.650E+02
Exposure Duration (y):       1.000E+00 Limiting Dose:              2.500E-02
-----------------------------------------------------------------------------
Site Parameters
-----------------------------------------------------------------------------
X Coordinate:                0.000E+00  Y Coordinate:               0.000E+00
Source Length (m):           5.180E+02  Source Width (m):           3.820E+02
Percolation Rate (m/y):      5.000E-03
Source Thickness (m):        1.060E+01  Src Bulk Density (g/cc):    1.260E+00
Source Moisture Content:     4.570E-02
-----------------------------------------------------------------------------
Unsaturated Zone Parameters
-----------------------------------------------------------------------------
Unsat Zone Thickness (m):    8.230E+01  Unsat Bulk Density:         1.600E+00
```

```
Unsat Dispersivity (m):      4.000E+00  Unsat Moisture Content:     4.570E-02
-----------------------------------------------------------------------------
Aquifer Zone Parameters
-----------------------------------------------------------------------------
Longitudinal Disp (m):       2.750E+01  Transverse Disp (m):        5.000E+00
Aquifer Thickness (m):       1.500E+01  Well Screen Thickness (m):  1.500E+01
Darcy Velocity (m/y):        3.290E+01  Aquifer Porosity:           1.000E-01
Bulk Density (g/cc):         1.600E+00
-----------------------------------------------------------------------------
Calculated Flow Parameters
-----------------------------------------------------------------------------
Percolation Water Flux (m3/y):  9.8938E+02
Unsat Pore Velocity (m/y):      1.0941E-01
Aquifer Pore Velocity (m/y):    3.2900E+02
Longitudinal Disp (m**2/y):     9.0475E+03
Transverse Disp (m**2/y):       1.6450E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:               I-129
 Number of Progeny:              0
 Half Life (y):                  1.570E+07
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):               3.000E-01
 Solubility Limit (mg/L):        1.000E+06
 Molecular Weight (mg/L):        1.290E+02
 Initial mass/activity:          6.012E+00
 Kd Unsat (ml/g):                3.000E-01
 Kd Aquifer (ml/g):              3.000E-01
 Risk/Dose Conversion Factor:    2.760E+05
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    4.4150E-08
Leach Rate Constant (1/y):                1.1133E-03
Initial Pore Water Conc (Ci or mg/m**3):  6.7649E-06
Solubility Limited Mass (mg):             8.8870E+14
Solubility Limited Act (Ci):              1.5700E+08
Unsaturated Retardation Factor:           1.1503E+01
Mean Unsaturated Transit Time (y):        8.6530E+03
Leading Edge Arrival Time (y):            1.3087E+03
Aquifer Retardation Factor:               5.800E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00
 8.0000E+02  3.364E-24  0.000E+00
 9.0000E+02  1.662E-21  0.000E+00
 1.0000E+03  2.336E-19  0.000E+00
 1.1000E+03  1.329E-17  0.000E+00
 1.3500E+03  2.313E-14  1.064E-19
 1.5000E+03  6.077E-13  2.873E-18
 1.6500E+03  8.719E-12  4.202E-17
 1.8000E+03  7.941E-11  3.885E-16
 1.9500E+03  5.098E-10  2.523E-15
 2.1000E+03  2.485E-09  1.241E-14
 2.2500E+03  9.714E-09  4.889E-14
 2.4000E+03  3.174E-08  1.607E-13
 2.5500E+03  8.947E-08  4.554E-13
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 2.7000E+03  2.229E-07  1.139E-12
 2.8500E+03  5.003E-07  2.567E-12
 3.2000E+03  2.389E-06  1.234E-11
 3.4000E+03  4.966E-06  2.573E-11
 3.6000E+03  9.403E-06  4.883E-11
 3.8000E+03  1.645E-05  8.562E-11
 4.0000E+03  2.693E-05  1.404E-10
 4.2000E+03  4.159E-05  2.172E-10
 4.4000E+03  6.112E-05  3.195E-10
 4.6000E+03  8.599E-05  4.501E-10
 4.8000E+03  1.165E-04  6.103E-10
 5.0000E+03  1.525E-04  7.999E-10
 5.2000E+03  1.939E-04  1.018E-09
 5.4000E+03  2.400E-04  1.261E-09
 5.6000E+03  2.901E-04  1.525E-09
 5.8000E+03  3.433E-04  1.805E-09
 6.2500E+03  4.684E-04  2.466E-09
 6.5000E+03  5.376E-04  2.832E-09
 6.7500E+03  6.039E-04  3.183E-09
 7.0000E+03  6.655E-04  3.509E-09
 7.2500E+03  7.207E-04  3.801E-09
 7.5000E+03  7.684E-04  4.054E-09
 7.7500E+03  8.077E-04  4.263E-09
 8.0000E+03  8.383E-04  4.426E-09
 8.2500E+03  8.599E-04  4.541E-09
 8.5000E+03  8.727E-04  4.609E-09
 8.7500E+03  8.770E-04  4.634E-09
 9.0000E+03  8.736E-04  4.616E-09
 9.2500E+03  8.629E-04  4.561E-09
 9.5000E+03  8.460E-04  4.472E-09
 9.7500E+03  8.236E-04  4.354E-09
 1.0000E+04  7.965E-04  4.212E-09
 1.0250E+04  7.657E-04  4.049E-09
Maximum Concentration and Time for Member #1:  4.634E-09  8.750E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                Tc-99
 Number of Progeny:               0
 Half Life (y):                   2.100E+05
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                0.000E+00
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         9.900E+01
 Initial mass/activity:           6.710E+01
 Kd Unsat (ml/g):                 0.000E+00
 Kd Aquifer (ml/g):               0.000E+00
 Risk/Dose Conversion Factor:     1.460E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                     3.3007E-06
Leach Rate Constant (1/y):                 1.0322E-02
Initial Pore Water Conc (Ci or mg/m**3):   7.0001E-04
Solubility Limited Mass (mg):              9.5855E+13
Solubility Limited Act (Ci):               1.6496E+09
Unsaturated Retardation Factor:            1.0000E+00
Mean Unsaturated Transit Time (y):         7.5222E+02
Leading Edge Arrival Time (y):             1.1377E+02
Aquifer Retardation Factor:                1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  1.560E-06  7.520E-12
 2.5000E+02  6.086E-05  3.037E-10
 3.0000E+02  6.372E-04  3.241E-09
 3.5000E+02  3.133E-03  1.612E-08
```

```
 4.0000E+02  9.578E-03  4.966E-08
 4.5000E+02  2.129E-02  1.110E-07
 5.0000E+02  3.782E-02  1.979E-07
 5.5000E+02  5.700E-02  2.991E-07
 7.0000E+02  1.029E-01  5.428E-07
 8.0000E+02  1.089E-01  5.756E-07
 9.0000E+02  9.750E-02  5.160E-07
 1.0000E+03  7.756E-02  4.109E-07
 1.1000E+03  5.657E-02  2.999E-07
 1.3500E+03  1.991E-02  1.057E-07
 1.5000E+03  9.459E-03  5.023E-08
 1.6500E+03  4.239E-03  2.252E-08
 1.8000E+03  1.818E-03  9.659E-09
 1.9500E+03  7.540E-04  4.007E-09
 2.1000E+03  3.047E-04  1.620E-09
 2.2500E+03  1.207E-04  6.414E-10
 2.4000E+03  4.700E-05  2.499E-10
 2.5500E+03  1.807E-05  9.609E-11
 2.7000E+03  6.874E-06  3.655E-11
 2.8500E+03  2.592E-06  1.378E-11
 3.2000E+03  2.593E-07  1.379E-12
 3.4000E+03  6.869E-08  3.653E-13
 3.6000E+03  1.807E-08  9.612E-14
 3.8000E+03  4.728E-09  2.515E-14
 4.0000E+03  1.231E-09  6.549E-15
 4.2000E+03  3.194E-10  1.699E-15
 4.4000E+03  8.261E-11  4.394E-16
 4.6000E+03  2.130E-11  1.133E-16
 4.8000E+03  5.482E-12  2.916E-17
 5.0000E+03  1.408E-12  7.489E-18
 5.2000E+03  3.610E-13  1.920E-18
 5.4000E+03  9.243E-14  4.917E-19
 5.6000E+03  2.364E-14  1.257E-19
 5.8000E+03  6.039E-15  3.212E-20
 6.2500E+03  2.793E-16  1.486E-21
 6.5000E+03  5.055E-17  2.689E-22
 6.7500E+03  9.142E-18  4.863E-23
 7.0000E+03  1.652E-18  8.789E-24
 7.2500E+03  2.984E-19  1.587E-24
 7.5000E+03  5.386E-20  2.865E-25
 7.7500E+03  9.716E-21  5.168E-26
 8.0000E+03  1.752E-21  9.321E-27
 8.2500E+03  3.159E-22  1.680E-27
 8.5000E+03  5.692E-23  3.028E-28
 8.7500E+03  1.017E-23  5.428E-29
 9.0000E+03  7.696E-25  4.108E-30
 9.2500E+03  5.824E-26  3.109E-31
 9.5000E+03  4.408E-27  2.353E-32
 9.7500E+03  3.336E-28  1.781E-33
 1.0000E+04  2.525E-29  1.348E-34
 1.0250E+04  1.911E-30  1.020E-35
Maximum Concentration and Time for Member #1:  5.756E-07  8.000E+02
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:               Cl-36
 Number of Progeny:              0
 Half Life (y):                  3.010E+05
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):               0.000E+00
 Solubility Limit (mg/L):        1.000E+06
 Molecular Weight (mg/L):        3.600E+01
 Initial mass/activity:          4.907E+00
 Kd Unsat (ml/g):                0.000E+00
 Kd Aquifer (ml/g):              0.000E+00
 Risk/Dose Conversion Factor:    3.030E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                    2.3028E-06
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Leach Rate Constant (1/y):              1.0322E-02
Initial Pore Water Conc (Ci or mg/m**3):  5.1192E-05
Solubility Limited Mass (mg):           9.5855E+13
Solubility Limited Act (Ci):            3.1650E+09
Unsaturated Retardation Factor:         1.0000E+00
Mean Unsaturated Transit Time (y):      7.5222E+02
Leading Edge Arrival Time (y):          1.1377E+02
Aquifer Retardation Factor:             1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  1.141E-07  5.501E-13
 2.5000E+02  4.452E-06  2.222E-11
 3.0000E+02  4.661E-05  2.371E-10
 3.5000E+02  2.292E-04  1.179E-09
 4.0000E+02  7.007E-04  3.633E-09
 4.5000E+02  1.558E-03  8.120E-09
 5.0000E+02  2.767E-03  1.448E-08
 5.5000E+02  4.171E-03  2.188E-08
 7.0000E+02  7.531E-03  3.972E-08
 8.0000E+02  7.971E-03  4.213E-08
 9.0000E+02  7.137E-03  3.777E-08
 1.0000E+03  5.677E-03  3.008E-08
 1.1000E+03  4.141E-03  2.196E-08
 1.3500E+03  1.458E-03  7.738E-09
 1.5000E+03  6.928E-04  3.679E-09
 1.6500E+03  3.105E-04  1.649E-09
 1.8000E+03  1.332E-04  7.076E-10
 1.9500E+03  5.524E-05  2.936E-10
 2.1000E+03  2.233E-05  1.187E-10
 2.2500E+03  8.843E-06  4.701E-11
 2.4000E+03  3.446E-06  1.832E-11
 2.5500E+03  1.325E-06  7.045E-12
 2.7000E+03  5.041E-07  2.680E-12
 2.8500E+03  1.901E-07  1.011E-12
 3.2000E+03  1.902E-08  1.012E-13
 3.4000E+03  5.040E-09  2.681E-14
 3.6000E+03  1.326E-09  7.055E-15
 3.8000E+03  3.471E-10  1.846E-15
 4.0000E+03  9.041E-11  4.809E-16
 4.2000E+03  2.346E-11  1.248E-16
 4.4000E+03  6.068E-12  3.227E-17
 4.6000E+03  1.565E-12  8.325E-18
 4.8000E+03  4.028E-13  2.143E-18
 5.0000E+03  1.035E-13  5.504E-19
 5.2000E+03  2.654E-14  1.412E-19
 5.4000E+03  6.796E-15  3.615E-20
 5.6000E+03  1.738E-15  9.247E-21
 5.8000E+03  4.442E-16  2.363E-21
 6.2500E+03  2.055E-17  1.093E-22
 6.5000E+03  3.721E-18  1.979E-23
 6.7500E+03  6.731E-19  3.580E-24
 7.0000E+03  1.217E-19  6.472E-25
 7.2500E+03  2.198E-20  1.169E-25
 7.5000E+03  3.968E-21  2.111E-26
 7.7500E+03  7.161E-22  3.809E-27
 8.0000E+03  1.292E-22  6.871E-28
 8.2500E+03  2.329E-23  1.239E-28
 8.5000E+03  4.198E-24  2.233E-29
 8.7500E+03  7.535E-25  4.020E-30
 9.0000E+03  5.704E-26  3.045E-31
 9.2500E+03  4.318E-27  2.305E-32
 9.5000E+03  3.269E-28  1.745E-33
 9.7500E+03  2.474E-29  1.321E-34
 1.0000E+04  1.873E-30  9.998E-36
 1.0250E+04  1.418E-31  7.569E-37
Maximum Concentration and Time for Member #1:  4.213E-08  8.000E+02
```

```
---------------------------------------------------------------------------
Contaminant Data
---------------------------------------------------------------------------
 Contaminant Name:               U-235
 Number of Progeny:              2
 Progeny Names:                 Pa-231       Ac-227
 Half Life (y):                  7.040E+08 3.280E+04 2.170E+01
 Other Source Loss Rate (1/y):   0.000E+00
 Kd Source (ml/g):               6.000E-01
 Solubility Limit (mg/L):        1.000E+00
 Molecular Weight (mg/L):        2.350E+02
 Initial mass/activity:          1.468E+04
 Kd Unsat (ml/g):                6.000E-01
 Kd Aquifer (ml/g):              6.000E-01 6.000E-01 1.000E+02
 Risk/Dose Conversion Factor:    2.670E+05 1.060E+03 1.480E+03
---------------------------------------------------------------------------
Calculated Contaminant Values
---------------------------------------------------------------------------
Decay Constants (1/y):                    9.8458E-10 2.1133E-05 3.1942E-02
Leach Rate Constant (1/y):                5.8837E-04
Initial Pore Water Conc (Ci or mg/m**3):  8.7300E-03
Solubility Limited Mass (mg):             1.6816E+09
Solubility Limited Act (Ci):              3.6366E+00
Solubility Limited Time (y):              6.8360E+06
Unsaturated Retardation Factor:           2.2007E+01
Mean Unsaturated Transit Time (y):        1.6554E+04
Leading Edge Arrival Time (y):            2.5037E+03
Aquifer Retardation Factor:               1.060E+01 1.060E+01 1.601E+03
---------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
---------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
---------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 8.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 9.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.0000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.1000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.3500E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 1.5000E+03  3.408E-25  0.000E+00  0.000E+00  0.000E+00
 1.6500E+03  6.282E-23  0.000E+00  0.000E+00  0.000E+00
 1.8000E+03  4.660E-21  0.000E+00  0.000E+00  0.000E+00
 1.9500E+03  1.777E-19  0.000E+00  0.000E+00  0.000E+00
 2.1000E+03  4.018E-18  0.000E+00  0.000E+00  0.000E+00
 2.2500E+03  5.979E-17  0.000E+00  0.000E+00  0.000E+00
 2.4000E+03  6.332E-16  0.000E+00  0.000E+00  0.000E+00
 2.5500E+03  5.068E-15  2.337E-20  1.226E-21  8.021E-24
 2.7000E+03  3.211E-14  1.504E-19  8.340E-21  5.459E-23
 2.8500E+03  1.671E-13  7.923E-19  4.631E-20  3.034E-22
 3.2000E+03  4.262E-12  2.067E-17  1.351E-18  8.862E-21
 3.4000E+03  2.000E-11  9.795E-17  6.791E-18  4.456E-20
 3.6000E+03  7.876E-11  3.889E-16  2.849E-17  1.870E-19
 3.8000E+03  2.675E-10  1.330E-15  1.026E-16  6.742E-19
 4.0000E+03  8.011E-10  4.008E-15  3.248E-16  2.135E-18
 4.2000E+03  2.154E-09  1.083E-14  9.200E-16  6.048E-18
 4.4000E+03  5.277E-09  2.666E-14  2.367E-15  1.556E-17
 4.6000E+03  1.192E-08  6.045E-14  5.600E-15  3.684E-17
 4.8000E+03  2.508E-08  1.277E-13  1.231E-14  8.102E-17
 5.0000E+03  4.959E-08  2.531E-13  2.538E-14  1.671E-16
 5.2000E+03  9.276E-08  4.748E-13  4.941E-14  3.253E-16
 5.4000E+03  1.652E-07  8.477E-13  9.142E-14  6.020E-16
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  5.6000E+03  2.816E-07  1.448E-12  1.616E-13  1.064E-15
  5.8000E+03  4.615E-07  2.378E-12  2.743E-13  1.807E-15
  6.2500E+03  1.239E-06  6.405E-12  7.925E-13  5.222E-15
  6.5000E+03  2.010E-06  1.041E-11  1.337E-12  8.810E-15
  6.7500E+03  3.137E-06  1.628E-11  2.164E-12  1.427E-14
  7.0000E+03  4.727E-06  2.456E-11  3.377E-12  2.227E-14
  7.2500E+03  6.901E-06  3.590E-11  5.100E-12  3.363E-14
  7.5000E+03  9.795E-06  5.102E-11  7.478E-12  4.932E-14
  7.7500E+03  1.355E-05  7.065E-11  1.067E-11  7.040E-14
  8.0000E+03  1.832E-05  9.559E-11  1.487E-11  9.809E-14
  8.2500E+03  2.425E-05  1.266E-10  2.026E-11  1.337E-13
  8.5000E+03  3.148E-05  1.646E-10  2.706E-11  1.785E-13
  8.7500E+03  4.017E-05  2.101E-10  3.547E-11  2.341E-13
  9.0000E+03  5.044E-05  2.640E-10  4.573E-11  3.018E-13
  9.2500E+03  6.241E-05  3.269E-10  5.804E-11  3.831E-13
  9.5000E+03  7.618E-05  3.992E-10  7.261E-11  4.793E-13
  9.7500E+03  9.184E-05  4.815E-10  8.966E-11  5.919E-13
  1.0000E+04  1.094E-04  5.741E-10  1.094E-10  7.220E-13
  1.0250E+04  1.290E-04  6.771E-10  1.319E-10  8.708E-13
 Maximum Concentration and Time for Member #1:  6.771E-10  1.025E+04
 Maximum Concentration and Time for Member #2:  1.319E-10  1.025E+04
 Maximum Concentration and Time for Member #3:  8.708E-13  1.025E+04
 -----------------------------------------------------------------------------
 Contaminant Data
 -----------------------------------------------------------------------------
  Contaminant Name:               U-238
  Number of Progeny:              4
  Progeny Names:                 U-234       Th-230       Ra-226       Pb-210
  Half Life (y):                  4.470E+09 2.440E+05 7.700E+04 1.600E+03 2.230E+01
  Other Source Loss Rate (1/y):   0.000E+00
  Kd Source (ml/g):               6.000E-01
  Solubility Limit (mg/L):        1.000E+00
  Molecular Weight (mg/L):        2.380E+02
  Initial mass/activity:          2.228E+04
  Kd Unsat (ml/g):                6.000E-01
  Kd Aquifer (ml/g):              6.000E-01 6.000E-01 4.000E+01 8.000E+00 2.000E+03
  Risk/Dose Conversion Factor:    2.690E+05 2.830E+05 5.480E+05 1.330E+06 7.270E+06
 -----------------------------------------------------------------------------
 Calculated Contaminant Values
 -----------------------------------------------------------------------------
 Decay Constants (1/y):                   1.5507E-10 2.8408E-06 9.0019E-06 4.3322E-04
3.1083E-02
 Leach Rate Constant (1/y):               5.8837E-04
 Initial Pore Water Conc (Ci or mg/m**3):  1.3250E-02
 Solubility Limited Mass (mg):            1.6816E+09
 Solubility Limited Act (Ci):             5.6553E-01
 Solubility Limited Time (y):             6.6612E+07
 Unsaturated Retardation Factor:          2.2007E+01
 Mean Unsaturated Transit Time (y):       1.6554E+04
 Leading Edge Arrival Time (y):           2.5037E+03
 Aquifer Retardation Factor:              1.060E+01 1.060E+01 6.410E+02 1.290E+02
3.200E+04
 -----------------------------------------------------------------------------
 Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
 -----------------------------------------------------------------------------
    Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3 Conc Mbr 4 Conc Mbr 5
  (years)  (mg or Ci/y) (mg or Ci per cubic meter)
 -----------------------------------------------------------------------------
  2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  3.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  4.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  4.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  5.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  5.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  7.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  8.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  9.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.0000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
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  1.1000E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.3500E+03  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.5000E+03  5.299E-26  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.6500E+03  9.769E-24  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.8000E+03  7.246E-22  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  1.9500E+03  2.763E-20  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.1000E+03  6.248E-19  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.2500E+03  9.298E-18  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.4000E+03  9.847E-17  0.000E+00  0.000E+00  0.000E+00  0.000E+00  0.000E+00
  2.5500E+03  7.881E-16  3.635E-21  2.623E-23  4.947E-27  7.032E-27  2.738E-29
  2.7000E+03  4.993E-15  2.338E-20  1.787E-22  3.566E-26  5.295E-26  2.066E-28
  2.8500E+03  2.599E-14  1.232E-19  9.936E-22  2.093E-25  3.235E-25  1.265E-27
  3.2000E+03  6.628E-13  3.214E-18  2.908E-20  6.871E-24  1.156E-23  4.536E-26
  3.4000E+03  3.111E-12  1.523E-17  1.464E-19  3.673E-23  6.455E-23  2.537E-25
  3.6000E+03  1.225E-11  6.047E-17  6.153E-19  1.634E-22  2.988E-22  1.176E-24
  3.8000E+03  4.160E-11  2.068E-16  2.221E-18  6.221E-22  1.181E-21  4.654E-24
  4.0000E+03  1.246E-10  6.232E-16  7.042E-18  2.075E-21  4.077E-21  1.609E-23
  4.2000E+03  3.350E-10  1.685E-15  1.998E-17  6.180E-21  1.254E-20  4.953E-23
  4.4000E+03  8.206E-10  4.145E-15  5.149E-17  1.668E-20  3.487E-20  1.379E-22
  4.6000E+03  1.854E-09  9.401E-15  1.220E-16  4.131E-20  8.883E-20  3.516E-22
  4.8000E+03  3.901E-09  1.985E-14  2.688E-16  9.490E-20  2.096E-19  8.303E-22
  5.0000E+03  7.712E-09  3.937E-14  5.552E-16  2.040E-19  4.620E-19  1.832E-21
  5.2000E+03  1.443E-08  7.384E-14  1.083E-15  4.136E-19  9.589E-19  3.805E-21
  5.4000E+03  2.569E-08  1.318E-13  2.007E-15  7.957E-19  1.886E-18  7.489E-21
  5.6000E+03  4.379E-08  2.252E-13  3.554E-15  1.461E-18  3.537E-18  1.405E-20
  5.8000E+03  7.177E-08  3.698E-13  6.043E-15  2.571E-18  6.350E-18  2.524E-20
  6.2500E+03  1.926E-07  9.961E-13  1.753E-14  8.027E-18  2.067E-17  8.223E-20
  6.5000E+03  3.126E-07  1.620E-12  2.963E-14  1.410E-17  3.708E-17  1.476E-19
  6.7500E+03  4.879E-07  2.531E-12  4.808E-14  2.375E-17  6.369E-17  2.537E-19
  7.0000E+03  7.351E-07  3.819E-12  7.520E-14  3.850E-17  1.052E-16  4.193E-19
  7.2500E+03  1.073E-06  5.584E-12  1.138E-13  6.031E-17  1.677E-16  6.688E-19
  7.5000E+03  1.523E-06  7.934E-12  1.672E-13  9.161E-17  2.591E-16  1.034E-18
  7.7500E+03  2.107E-06  1.099E-11  2.392E-13  1.353E-16  3.889E-16  1.552E-18
  8.0000E+03  2.849E-06  1.487E-11  3.340E-13  1.949E-16  5.687E-16  2.270E-18
  8.2500E+03  3.770E-06  1.969E-11  4.562E-13  2.744E-16  8.119E-16  3.242E-18
  8.5000E+03  4.896E-06  2.559E-11  6.106E-13  3.781E-16  1.134E-15  4.530E-18
  8.7500E+03  6.247E-06  3.268E-11  8.023E-13  5.111E-16  1.553E-15  6.206E-18
  9.0000E+03  7.844E-06  4.106E-11  1.036E-12  6.788E-16  2.088E-15  8.346E-18
  9.2500E+03  9.706E-06  5.083E-11  1.318E-12  8.868E-16  2.760E-15  1.104E-17
  9.5000E+03  1.185E-05  6.208E-11  1.653E-12  1.141E-15  3.593E-15  1.437E-17
  9.7500E+03  1.428E-05  7.488E-11  2.046E-12  1.448E-15  4.609E-15  1.844E-17
  1.0000E+04  1.702E-05  8.927E-11  2.500E-12  1.815E-15  5.835E-15  2.334E-17
  1.0250E+04  2.007E-05  1.053E-10  3.022E-12  2.247E-15  7.295E-15  2.919E-17
 Maximum Concentration and Time for Member #1:  1.053E-10  1.025E+04
 Maximum Concentration and Time for Member #2:  3.022E-12  1.025E+04
 Maximum Concentration and Time for Member #3:  2.247E-15  1.025E+04
 Maximum Concentration and Time for Member #4:  7.295E-15  1.025E+04
 Maximum Concentration and Time for Member #5:  2.919E-17  1.025E+04
 Execution Time (Seconds):    3
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Site Soils Cover Input File

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Washington State PA Site Soils Cover Infiltration 0.02 m/y and no shadow            (Card
1)
1 1 0 2 1                       (Card 2) imode,itype,idisp,kflag idil
1 2 1 2 1                       (Card 3) imodel,isolve,isolveu,imoist,imoistu
6 13 0.01                      (Card 4) jstart jmax eps
70. 2.555E+04 2.0  365.  1.  0.025    (Card 5) bw,at,wi,ef,ed,dlim
0.  0.                          (Card 6) x0,y0
518.  382.  0.02                (Card 7) l,w,perc
10.6 1.26                       (Card 8b) thicks,rhos
$ 0.0457                           (Card 8c) thetas
7.51  2.298 1710. 0.2724 0.0321       (Card 8d) alpha n ksat pors thetar
329.  1.6  16.                   (Card 9) depth,rhou,axu
$ 7.51  2.298 1710. 0.2724 0.0321      (Card 9b) alpha n ksat pors thetar
0.0457                           (Card 9c) thetau
27.5  5.  5.0e-1   15.  15.         (Card 10) ax,ay,az,b,z
32.9  0.1  1.6                  (Card 11) u,phi,rhoa
1                               (Card 12a nrecept
275.  0.                        (Card 12b) xrec(i) yrec(i)
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6                                    (Card 13a)
200.  600.  50.                     (Card 13b)
700.  1200. 100.
1350. 3000. 150.
3200. 6000. 200.
6250. 10500. 250.
11000. 30000. 1000.
5                                    (Card 14) ncontam
$ I-129
0  0.3 0.3  129.  6.012  0.0 1.0e6 0.0 (Card 14a) nprog kds kdu zmw q0 rmi sl other
I-129 1.57E7 0.3 2.76e5                (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ Tc-99
0   0.0  0.0  99. 67.1   0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Tc-99 2.10E5 0.0 1460.                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ CL-36
0   0.0  0.0  36. 4.907  0.0 1.0e6 0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
Cl-36 3.01E5 0.0 3030                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-235
2   0.6 0.6 235. 1.468E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-235  7.04E8 0.6 2.67e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pa-231 3.28E4 0.6 1.06e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ac-227 2.17E1 100. 1.48e3                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
$ U-238
4   0.6 0.6 238. 2.228E4  0.0 1.0   0.0  (Card 14a) nprog kds kdu zmw q0 rmi sl other
U-238  4.47E9 0.6 2.69e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
U-234  2.44E5 0.6 2.83e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Th-230 7.70E4 40. 5.48e5                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Ra-226 1.60E3 8.  1.33e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
Pb-210 2.23E1 2000. 7.27e6                  (Card 14b) cname(i),thalf(i),kda(i),dcf(i)
```

Site Soils Cover Output File

```
 TIME OF RUN: 09:23:15.60  DATE OF RUN: 03/09/:0
   ***************************************************
   *                                                 *
   *     This output was produced by the model:      *
   *                                                 *
   *                    GWSCREEN                     *
   *                   Version 2.5a                  *
   *    A semi-analytical model for the assessment   *
   *    of the groundwater pathway from the leaching *
   *    of surficial and buried contamination and    *
   *  release of contaminants from percolation ponds *
   *                   01/04/2000                    *
   *                  Arthur S. Rood                 *
   *         Idaho National Engineering and          *
   *            Environmental Laboratory             *
   *                   PO Box 1625                   *
   *              Idaho Falls, Idaho 83415           *
   ***************************************************
  ============================================================================
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                    LIMITATION OF LIABILITY

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  DOE Field Office, Idaho, Contract Number DE-AC07-76ID01570.
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  Cambridge University Press.
  ===========================================================================
```

```
OUTPUT FILE NAME: sscover.out
INPUT FILE NAME: sscover.par
Title: Washington State PA Site Soils Cover Infiltration 0.02 m/y and no shadow
------------------------------------------------------------------------------
Model Run Options
------------------------------------------------------------------------------
IMODE Contaminant Type and Impacts:                            1
ITYPE (1) Vert Avg (2) 3D Point (3) 3d Avg:                    1
IDISP (0) Fixed Dispersivity (1-3) Spatially Varying:          0
KFLAG (1) Max Conc (2) Conc vs Time (3) Grid Output:           2
IDIL (1) No dilution factor (2) Include Dilution Factor:       1
IMOIST Source Moisture Content Option:                         2
IMOISTU Unsaturated Moisture Content Option:                   1
IMODEL (1) Surface/Burried Src (2) Pond (3) Usr Def:           1
ISOLVE (1) Gaussian Quarature (2) Simpsons Rule: (Aquifer)     2
ISOLVEU (1) Gaussian Quarature (2) Simpsons Rule: (Unsat Zone)  1
JSTART:   6
JMAX  :  13
EPS   :  1.000E-02
Health Effects: Committed effective dose equivalent calculation
Output mass/activity units:   Ci
Output concentration units:   Ci/m**3
Dose/Risk Conversion Units:   rem/Ci
Output health effects units:  rem
------------------------------------------------------------------------------
Exposure Parameters
------------------------------------------------------------------------------
Body Mass (kg):              70.       Averaging Time (days):      25550.
Water Ingestion (L/d):       2.000E+00 Exposure Freq (day/year):   3.650E+02
Exposure Duration (y):       1.000E+00 Limiting Dose:              2.500E-02
------------------------------------------------------------------------------
Site Parameters
------------------------------------------------------------------------------
X Coordinate:                0.000E+00  Y Coordinate:               0.000E+00
Source Length (m):           5.180E+02  Source Width (m):           3.820E+02
Percolation Rate (m/y):      2.000E-02
Source Thickness (m):        1.060E+01  Src Bulk Density (g/cc):    1.260E+00
Source Alpha (1/m):          7.510E+00  Source n:                   2.298E+00
Saturated K in Src (m/y):    1.710E+03  Porosity of Source:         2.724E-01
Source Residuale Moisture:   3.210E-02
------------------------------------------------------------------------------
Unsaturated Zone Parameters
------------------------------------------------------------------------------
Unsat Zone Thickness (m):    3.290E+02  Unsat Bulk Density:         1.600E+00
Unsat Dispersivity (m):      1.600E+01  Unsat Moisture Content:     4.570E-02
------------------------------------------------------------------------------
Aquifer Zone Parameters
------------------------------------------------------------------------------
Longitudinal Disp (m):       2.750E+01  Transverse Disp (m):        5.000E+00
Aquifer Thickness (m):       1.500E+01  Well Screen Thickness (m):  1.500E+01
Darcy Velocity (m/y):        3.290E+01  Aquifer Porosity:           1.000E-01
Bulk Density (g/cc):         1.600E+00
------------------------------------------------------------------------------
Calculated Flow Parameters
------------------------------------------------------------------------------
Percolation Water Flux (m3/y):  3.9575E+03
Source Moisture Content:        5.1263E-02
Unsat Pore Velocity (m/y):      4.3764E-01
Aquifer Pore Velocity (m/y):    3.2900E+02
Longitudinal Disp (m**2/y):     9.0475E+03
Transverse Disp (m**2/y):       1.6450E+03
------------------------------------------------------------------------------
Contaminant Data
------------------------------------------------------------------------------
 Contaminant Name:              I-129
 Number of Progeny:             0
 Half Life (y):                 1.570E+07
 Other Source Loss Rate (1/y):  0.000E+00
 Kd Source (ml/g):              3.000E-01
 Solubility Limit (mg/L):       1.000E+06
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 Molecular Weight (mg/L):        1.290E+02
 Initial mass/activity:          6.012E+00
 Kd Unsat (ml/g):                3.000E-01
 Kd Aquifer (ml/g):              3.000E-01
 Risk/Dose Conversion Factor:    2.760E+05
------------------------------------------------------------------------------
Calculated Contaminant Values
------------------------------------------------------------------------------
Decay Constants (1/y):                     4.4150E-08
Leach Rate Constant (1/y):                 4.3954E-03
Initial Pore Water Conc (Ci or mg/m**3):  6.6772E-06
Solubility Limited Mass (mg):              9.0037E+14
Solubility Limited Act (Ci):               1.5906E+08
Unsaturated Retardation Factor:            1.1503E+01
Mean Unsaturated Transit Time (y):         8.6478E+03
Leading Edge Arrival Time (y):             1.3073E+03
Aquifer Retardation Factor:                5.800E+00
------------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
------------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
------------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00
 4.0000E+02  0.000E+00  0.000E+00
 4.5000E+02  0.000E+00  0.000E+00
 5.0000E+02  0.000E+00  0.000E+00
 5.5000E+02  0.000E+00  0.000E+00
 7.0000E+02  0.000E+00  0.000E+00
 8.0000E+02  1.357E-23  0.000E+00
 9.0000E+02  6.558E-21  0.000E+00
 1.0000E+03  9.052E-19  0.000E+00
 1.1000E+03  5.058E-17  0.000E+00
 1.3500E+03  8.413E-14  3.873E-19
 1.5000E+03  2.149E-12  1.014E-17
 1.6500E+03  2.996E-11  1.442E-16
 1.8000E+03  2.649E-10  1.294E-15
 1.9500E+03  1.650E-09  8.152E-15
 2.1000E+03  7.796E-09  3.889E-14
 2.2500E+03  2.954E-08  1.485E-13
 2.4000E+03  9.350E-08  4.728E-13
 2.5500E+03  2.552E-07  1.297E-12
 2.7000E+03  6.155E-07  3.142E-12
 2.8500E+03  1.338E-06  6.854E-12
 3.2000E+03  5.922E-06  3.055E-11
 3.4000E+03  1.179E-05  6.101E-11
 3.6000E+03  2.140E-05  1.110E-10
 3.8000E+03  3.591E-05  1.866E-10
 4.0000E+03  5.638E-05  2.935E-10
 4.2000E+03  8.362E-05  4.360E-10
 4.4000E+03  1.181E-04  6.166E-10
 4.6000E+03  1.598E-04  8.353E-10
 4.8000E+03  2.084E-04  1.090E-09
 5.0000E+03  2.629E-04  1.377E-09
 5.2000E+03  3.224E-04  1.690E-09
 5.4000E+03  3.853E-04  2.021E-09
 5.6000E+03  4.501E-04  2.362E-09
 5.8000E+03  5.152E-04  2.706E-09
 6.2500E+03  6.550E-04  3.443E-09
 6.5000E+03  7.243E-04  3.809E-09
 6.7500E+03  7.849E-04  4.130E-09
 7.0000E+03  8.357E-04  4.399E-09
 7.2500E+03  8.756E-04  4.611E-09
 7.5000E+03  9.045E-04  4.764E-09
 7.7500E+03  9.224E-04  4.860E-09
 8.0000E+03  9.299E-04  4.901E-09
 8.2500E+03  9.277E-04  4.890E-09
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 8.5000E+03  9.167E-04  4.833E-09
 8.7500E+03  8.981E-04  4.736E-09
 9.0000E+03  8.729E-04  4.604E-09
 9.2500E+03  8.423E-04  4.443E-09
 9.5000E+03  8.074E-04  4.260E-09
 9.7500E+03  7.693E-04  4.059E-09
 1.0000E+04  7.289E-04  3.847E-09
 1.0250E+04  6.870E-04  3.626E-09
 1.1000E+04  5.599E-04  2.956E-09
 1.2000E+04  4.043E-04  2.135E-09
 1.3000E+04  2.787E-04  1.472E-09
 1.4000E+04  1.853E-04  9.788E-10
 1.5000E+04  1.197E-04  6.326E-10
 1.6000E+04  7.561E-05  3.996E-10
 1.7000E+04  4.688E-05  2.478E-10
 1.8000E+04  2.863E-05  1.513E-10
 1.9000E+04  1.727E-05  9.127E-11
 2.0000E+04  1.030E-05  5.446E-11
 2.1000E+04  6.092E-06  3.220E-11
 2.2000E+04  3.575E-06  1.890E-11
 2.3000E+04  2.084E-06  1.102E-11
 2.4000E+04  1.208E-06  6.387E-12
 2.5000E+04  6.968E-07  3.684E-12
 2.6000E+04  4.002E-07  2.116E-12
 2.7000E+04  2.289E-07  1.211E-12
 2.8000E+04  1.305E-07  6.903E-13
 2.9000E+04  7.422E-08  3.924E-13
Maximum Concentration and Time for Member #1:  4.901E-09  8.000E+03
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:                Tc-99
 Number of Progeny:               0
 Half Life (y):                   2.100E+05
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                0.000E+00
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         9.900E+01
 Initial mass/activity:           6.710E+01
 Kd Unsat (ml/g):                 0.000E+00
 Kd Aquifer (ml/g):               0.000E+00
 Risk/Dose Conversion Factor:     1.460E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                     3.3007E-06
Leach Rate Constant (1/y):                 3.6806E-02
Initial Pore Water Conc (Ci or mg/m**3):   6.2405E-04
Solubility Limited Mass (mg):              1.0752E+14
Solubility Limited Act (Ci):               1.8505E+09
Unsaturated Retardation Factor:            1.0000E+00
Mean Unsaturated Transit Time (y):         7.5176E+02
Leading Edge Arrival Time (y):             1.1365E+02
Aquifer Retardation Factor:                1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  4.570E-06  2.201E-11
 2.5000E+02  1.615E-04  8.053E-10
 3.0000E+02  1.525E-03  7.753E-09
 3.5000E+02  6.758E-03  3.476E-08
 4.0000E+02  1.865E-02  9.666E-08
 4.5000E+02  3.754E-02  1.956E-07
 5.0000E+02  6.063E-02  3.170E-07
 5.5000E+02  8.348E-02  4.377E-07
 7.0000E+02  1.186E-01  6.250E-07
 8.0000E+02  1.098E-01  5.794E-07
```

```
 9.0000E+02  8.753E-02  4.626E-07
 1.0000E+03  6.302E-02  3.333E-07
 1.1000E+03  4.218E-02  2.233E-07
 1.3500E+03  1.258E-02  6.662E-08
 1.5000E+03  5.550E-03  2.941E-08
 1.6500E+03  2.343E-03  1.242E-08
 1.8000E+03  9.574E-04  5.076E-09
 1.9500E+03  3.818E-04  2.025E-09
 2.1000E+03  1.494E-04  7.924E-10
 2.2500E+03  5.762E-05  3.056E-10
 2.4000E+03  2.196E-05  1.165E-10
 2.5500E+03  8.291E-06  4.398E-11
 2.7000E+03  3.106E-06  1.648E-11
 2.8500E+03  1.156E-06  6.134E-12
 3.2000E+03  1.131E-07  5.999E-13
 3.4000E+03  2.967E-08  1.574E-13
 3.6000E+03  7.746E-09  4.110E-14
 3.8000E+03  2.013E-09  1.068E-14
 4.0000E+03  5.215E-10  2.767E-15
 4.2000E+03  1.347E-10  7.147E-16
 4.4000E+03  3.470E-11  1.841E-16
 4.6000E+03  8.921E-12  4.734E-17
 4.8000E+03  2.289E-12  1.215E-17
 5.0000E+03  5.866E-13  3.113E-18
 5.2000E+03  1.501E-13  7.965E-19
 5.4000E+03  3.837E-14  2.036E-19
 5.6000E+03  9.797E-15  5.199E-20
 5.8000E+03  2.499E-15  1.326E-20
 6.2500E+03  1.153E-16  6.120E-22
 6.5000E+03  2.085E-17  1.107E-22
 6.7500E+03  3.768E-18  2.000E-23
 7.0000E+03  6.805E-19  3.611E-24
 7.2500E+03  1.228E-19  6.517E-25
 7.5000E+03  2.215E-20  1.176E-25
 7.7500E+03  3.995E-21  2.120E-26
 8.0000E+03  7.201E-22  3.821E-27
 8.2500E+03  1.298E-22  6.886E-28
 8.5000E+03  2.338E-23  1.241E-28
 8.7500E+03  3.814E-24  2.086E-29
 9.0000E+03  3.845E-28  2.103E-33
 9.2500E+03  3.876E-32  2.120E-37
 9.5000E+03  3.907E-36  2.137E-41
 9.7500E+03  3.939E-40  2.154E-45
 1.0000E+04  3.971E-44  2.172E-49
 1.0250E+04  4.003E-48  2.189E-53
 1.1000E+04  4.101E-60  2.243E-65
 1.2000E+04  4.235E-76  2.316E-81
 1.3000E+04  4.373E-92  2.392E-97
 1.4000E+04  4.516-108  2.470-113
 1.5000E+04  4.664-124  2.551-129
 1.6000E+04  4.817-140  2.634-145
 1.7000E+04  4.974-156  2.721-161
 1.8000E+04  5.137-172  2.810-177
 1.9000E+04  5.305-188  2.902-193
 2.0000E+04  5.479-204  2.997-209
 2.1000E+04  5.658-220  3.095-225
 2.2000E+04  5.843-236  3.196-241
 2.3000E+04  0.000E+00  0.000E+00
 2.4000E+04  0.000E+00  0.000E+00
 2.5000E+04  0.000E+00  0.000E+00
 2.6000E+04  0.000E+00  0.000E+00
 2.7000E+04  0.000E+00  0.000E+00
 2.8000E+04  0.000E+00  0.000E+00
 2.9000E+04  0.000E+00  0.000E+00
Maximum Concentration and Time for Member #1:  6.250E-07  7.000E+02
-----------------------------------------------------------------------------
Contaminant Data
-----------------------------------------------------------------------------
 Contaminant Name:             Cl-36
 Number of Progeny:            0
```

```
 Half Life (y):                   3.010E+05
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                0.000E+00
 Solubility Limit (mg/L):         1.000E+06
 Molecular Weight (mg/L):         3.600E+01
 Initial mass/activity:           4.907E+00
 Kd Unsat (ml/g):                 0.000E+00
 Kd Aquifer (ml/g):               0.000E+00
 Risk/Dose Conversion Factor:     3.030E+03
-----------------------------------------------------------------------------
Calculated Contaminant Values
-----------------------------------------------------------------------------
Decay Constants (1/y):                     2.3028E-06
Leach Rate Constant (1/y):                 3.6806E-02
Initial Pore Water Conc (Ci or mg/m**3):  4.5636E-05
Solubility Limited Mass (mg):              1.0752E+14
Solubility Limited Act (Ci):               3.5503E+09
Unsaturated Retardation Factor:            1.0000E+00
Mean Unsaturated Transit Time (y):         7.5176E+02
Leading Edge Arrival Time (y):             1.1365E+02
Aquifer Retardation Factor:                1.000E+00
-----------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-----------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-----------------------------------------------------------------------------
 2.0000E+02  3.343E-07  1.610E-12
 2.5000E+02  1.181E-05  5.891E-11
 3.0000E+02  1.116E-04  5.671E-10
 3.5000E+02  4.944E-04  2.543E-09
 4.0000E+02  1.364E-03  7.071E-09
 4.5000E+02  2.747E-03  1.431E-08
 5.0000E+02  4.436E-03  2.319E-08
 5.5000E+02  6.108E-03  3.203E-08
 7.0000E+02  8.680E-03  4.574E-08
 8.0000E+02  8.034E-03  4.241E-08
 9.0000E+02  6.407E-03  3.386E-08
 1.0000E+03  4.613E-03  2.440E-08
 1.1000E+03  3.088E-03  1.635E-08
 1.3500E+03  9.208E-04  4.879E-09
 1.5000E+03  4.065E-04  2.154E-09
 1.6500E+03  1.716E-04  9.098E-10
 1.8000E+03  7.014E-05  3.719E-10
 1.9500E+03  2.797E-05  1.483E-10
 2.1000E+03  1.095E-05  5.807E-11
 2.2500E+03  4.223E-06  2.240E-11
 2.4000E+03  1.610E-06  8.539E-12
 2.5500E+03  6.078E-07  3.224E-12
 2.7000E+03  2.278E-07  1.208E-12
 2.8500E+03  8.480E-08  4.499E-13
 3.2000E+03  8.295E-09  4.401E-14
 3.4000E+03  2.177E-09  1.155E-14
 3.6000E+03  5.685E-10  3.016E-15
 3.8000E+03  1.478E-10  7.842E-16
 4.0000E+03  3.829E-11  2.032E-16
 4.2000E+03  9.891E-12  5.248E-17
 4.4000E+03  2.549E-12  1.352E-17
 4.6000E+03  6.554E-13  3.478E-18
 4.8000E+03  1.682E-13  8.926E-19
 5.0000E+03  4.311E-14  2.288E-19
 5.2000E+03  1.103E-14  5.855E-20
 5.4000E+03  2.821E-15  1.497E-20
 5.6000E+03  7.205E-16  3.823E-21
 5.8000E+03  1.838E-16  9.756E-22
 6.2500E+03  8.487E-18  4.503E-23
 6.5000E+03  1.535E-18  8.146E-24
 6.7500E+03  2.774E-19  1.472E-24
 7.0000E+03  5.011E-20  2.659E-25
 7.2500E+03  9.046E-21  4.801E-26
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 7.5000E+03  1.632E-21  8.662E-27
 7.7500E+03  2.944E-22  1.562E-27
 8.0000E+03  5.309E-23  2.817E-28
 8.2500E+03  9.569E-24  5.078E-29
 8.5000E+03  1.724E-24  9.150E-30
 8.7500E+03  2.924E-25  1.598E-30
 9.0000E+03  2.949E-29  1.613E-34
 9.2500E+03  2.973E-33  1.626E-38
 9.5000E+03  2.998E-37  1.640E-42
 9.7500E+03  3.023E-41  1.653E-46
 1.0000E+04  3.048E-45  1.667E-50
 1.0250E+04  3.073E-49  1.681E-54
 1.1000E+04  3.151E-61  1.723E-66
 1.2000E+04  3.257E-77  1.782E-82
 1.3000E+04  3.367E-93  1.842E-98
 1.4000E+04  3.481-109  1.904-114
 1.5000E+04  3.598-125  1.968-130
 1.6000E+04  3.720-141  2.034-146
 1.7000E+04  3.845-157  2.103-162
 1.8000E+04  3.975-173  2.174-178
 1.9000E+04  4.109-189  2.247-194
 2.0000E+04  4.248-205  2.323-210
 2.1000E+04  4.391-221  2.402-226
 2.2000E+04  4.539-237  2.483-242
 2.3000E+04  0.000E+00  0.000E+00
 2.4000E+04  0.000E+00  0.000E+00
 2.5000E+04  0.000E+00  0.000E+00
 2.6000E+04  0.000E+00  0.000E+00
 2.7000E+04  0.000E+00  0.000E+00
 2.8000E+04  0.000E+00  0.000E+00
 2.9000E+04  0.000E+00  0.000E+00
Maximum Concentration and Time for Member #1:  4.574E-08  7.000E+02
-------------------------------------------------------------------------------
Contaminant Data
-------------------------------------------------------------------------------
 Contaminant Name:                U-235
 Number of Progeny:               2
 Progeny Names:                  Pa-231       Ac-227
 Half Life (y):                   7.040E+08 3.280E+04 2.170E+01
 Other Source Loss Rate (1/y):    0.000E+00
 Kd Source (ml/g):                6.000E-01
 Solubility Limit (mg/L):         1.000E+00
 Molecular Weight (mg/L):         2.350E+02
 Initial mass/activity:           1.468E+04
 Kd Unsat (ml/g):                 6.000E-01
 Kd Aquifer (ml/g):               6.000E-01 6.000E-01 1.000E+02
 Risk/Dose Conversion Factor:     2.670E+05 1.060E+03 1.480E+03
-------------------------------------------------------------------------------
Calculated Contaminant Values
-------------------------------------------------------------------------------
Decay Constants (1/y):                     9.8458E-10 2.1133E-05 3.1942E-02
Leach Rate Constant (1/y):                 2.3373E-03
Initial Pore Water Conc (Ci or mg/m**3):  8.6699E-03
Solubility Limited Mass (mg):              1.6932E+09
Solubility Limited Act (Ci):               3.6619E+00
Solubility Limited Time (y):               1.7133E+06
Unsaturated Retardation Factor:            2.2007E+01
Mean Unsaturated Transit Time (y):         1.6544E+04
Leading Edge Arrival Time (y):             2.5010E+03
Aquifer Retardation Factor:                1.060E+01 1.060E+01 1.601E+03
-------------------------------------------------------------------------------
Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
-------------------------------------------------------------------------------
   Time        Flux     Conc Mbr 1 Conc Mbr 2 Conc Mbr 3
 (years)  (mg or Ci/y) (mg or Ci per cubic meter)
-------------------------------------------------------------------------------
 2.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 2.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.0000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
 3.5000E+02  0.000E+00  0.000E+00  0.000E+00  0.000E+00
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4.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.0000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.1000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.3500E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.5000E+03	1.456E-24	0.000E+00	0.000E+00	0.000E+00
1.6500E+03	2.660E-22	0.000E+00	0.000E+00	0.000E+00
1.8000E+03	1.963E-20	0.000E+00	0.000E+00	0.000E+00
1.9500E+03	7.453E-19	0.000E+00	0.000E+00	0.000E+00
2.1000E+03	1.679E-17	0.000E+00	0.000E+00	0.000E+00
2.2500E+03	2.490E-16	0.000E+00	0.000E+00	0.000E+00
2.4000E+03	2.630E-15	0.000E+00	0.000E+00	0.000E+00
2.5500E+03	2.099E-14	9.669E-20	5.072E-21	3.318E-23
2.7000E+03	1.327E-13	6.201E-19	3.439E-20	2.251E-22
2.8500E+03	6.893E-13	3.260E-18	1.905E-19	1.248E-21
3.2000E+03	1.751E-11	8.469E-17	5.538E-18	3.632E-20
3.4000E+03	8.203E-11	4.006E-16	2.778E-17	1.823E-19
3.6000E+03	3.224E-10	1.588E-15	1.163E-16	7.638E-19
3.8000E+03	1.093E-09	5.423E-15	4.185E-16	2.749E-18
4.0000E+03	3.270E-09	1.632E-14	1.323E-15	8.692E-18
4.2000E+03	8.783E-09	4.405E-14	3.742E-15	2.460E-17
4.4000E+03	2.149E-08	1.083E-13	9.615E-15	6.323E-17
4.6000E+03	4.850E-08	2.453E-13	2.273E-14	1.495E-16
4.8000E+03	1.020E-07	5.176E-13	4.993E-14	3.285E-16
5.0000E+03	2.014E-07	1.026E-12	1.028E-13	6.768E-16
5.2000E+03	3.765E-07	1.922E-12	2.000E-13	1.317E-15
5.4000E+03	6.700E-07	3.429E-12	3.698E-13	2.435E-15
5.6000E+03	1.141E-06	5.854E-12	6.534E-13	4.303E-15
5.8000E+03	1.869E-06	9.606E-12	1.108E-12	7.300E-15
6.2500E+03	5.010E-06	2.584E-11	3.198E-12	2.107E-14
6.5000E+03	8.126E-06	4.200E-11	5.390E-12	3.553E-14
6.7500E+03	1.267E-05	6.560E-11	8.721E-12	5.749E-14
7.0000E+03	1.909E-05	9.893E-11	1.360E-11	8.969E-14
7.2500E+03	2.785E-05	1.445E-10	2.053E-11	1.354E-13
7.5000E+03	3.951E-05	2.053E-10	3.009E-11	1.985E-13
7.7500E+03	5.464E-05	2.842E-10	4.293E-11	2.832E-13
8.0000E+03	7.383E-05	3.844E-10	5.978E-11	3.944E-13
8.2500E+03	9.769E-05	5.090E-10	8.143E-11	5.373E-13
8.5000E+03	1.268E-04	6.612E-10	1.087E-10	7.174E-13
8.7500E+03	1.617E-04	8.440E-10	1.425E-10	9.403E-13
9.0000E+03	2.030E-04	1.060E-09	1.836E-10	1.212E-12
9.2500E+03	2.511E-04	1.312E-09	2.330E-10	1.538E-12
9.5000E+03	3.065E-04	1.602E-09	2.914E-10	1.924E-12
9.7500E+03	3.693E-04	1.932E-09	3.597E-10	2.375E-12
1.0000E+04	4.400E-04	2.302E-09	4.386E-10	2.896E-12
1.0250E+04	5.187E-04	2.715E-09	5.288E-10	3.492E-12
1.1000E+04	8.028E-04	4.207E-09	8.727E-10	5.763E-12
1.2000E+04	1.289E-03	6.761E-09	1.514E-09	1.000E-11
1.3000E+04	1.876E-03	9.853E-09	2.367E-09	1.564E-11
1.4000E+04	2.533E-03	1.331E-08	3.410E-09	2.253E-11
1.5000E+04	3.224E-03	1.695E-08	4.605E-09	3.044E-11
1.6000E+04	3.914E-03	2.059E-08	5.907E-09	3.905E-11
1.7000E+04	4.577E-03	2.409E-08	7.269E-09	4.805E-11
1.8000E+04	5.192E-03	2.733E-08	8.648E-09	5.717E-11
1.9000E+04	5.748E-03	3.026E-08	1.001E-08	6.617E-11
2.0000E+04	6.238E-03	3.285E-08	1.132E-08	7.487E-11
2.1000E+04	6.662E-03	3.509E-08	1.257E-08	8.316E-11
2.2000E+04	7.022E-03	3.699E-08	1.375E-08	9.096E-11
2.3000E+04	7.324E-03	3.858E-08	1.485E-08	9.823E-11
2.4000E+04	7.574E-03	3.990E-08	1.587E-08	1.050E-10
2.5000E+04	7.778E-03	4.098E-08	1.682E-08	1.113E-10
2.6000E+04	7.943E-03	4.186E-08	1.769E-08	1.170E-10
2.7000E+04	8.077E-03	4.256E-08	1.851E-08	1.224E-10
2.8000E+04	8.183E-03	4.312E-08	1.926E-08	1.274E-10
2.9000E+04	8.267E-03	4.356E-08	1.996E-08	1.321E-10

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 Maximum Concentration and Time for Member #1:  4.356E-08  2.900E+04
 Maximum Concentration and Time for Member #2:  1.996E-08  2.900E+04
 Maximum Concentration and Time for Member #3:  1.321E-10  2.900E+04
 ---------------------------------------------------------------------------
 Contaminant Data
 ---------------------------------------------------------------------------
  Contaminant Name:               U-238
  Number of Progeny:              4
  Progeny Names:                 U-234       Th-230      Ra-226      Pb-210
  Half Life (y):                  4.470E+09 2.440E+05 7.700E+04 1.600E+03 2.230E+01
  Other Source Loss Rate (1/y):   0.000E+00
  Kd Source (ml/g):               6.000E-01
  Solubility Limit (mg/L):        1.000E+00
  Molecular Weight (mg/L):        2.380E+02
  Initial mass/activity:          2.228E+04
  Kd Unsat (ml/g):                6.000E-01
  Kd Aquifer (ml/g):              6.000E-01 6.000E-01 4.000E+01 8.000E+00 2.000E+03
  Risk/Dose Conversion Factor:    2.690E+05 2.830E+05 5.480E+05 1.330E+06 7.270E+06
 ---------------------------------------------------------------------------
 Calculated Contaminant Values
 ---------------------------------------------------------------------------
 Decay Constants (1/y):                   1.5507E-10 2.8408E-06 9.0019E-06 4.3322E-04
3.1083E-02
 Leach Rate Constant (1/y):               2.3373E-03
 Initial Pore Water Conc (Ci or mg/m**3): 1.3158E-02
 Solubility Limited Mass (mg):            1.6932E+09
 Solubility Limited Act (Ci):             5.6946E-01
 Solubility Limited Time (y):             1.6718E+07
 Unsaturated Retardation Factor:          2.2007E+01
 Mean Unsaturated Transit Time (y):       1.6544E+04
 Leading Edge Arrival Time (y):           2.5010E+03
 Aquifer Retardation Factor:              1.060E+01 1.060E+01 6.410E+02 1.290E+02
3.200E+04
 ---------------------------------------------------------------------------
 Concentration vs Time Results for Receptor X =  2.75000E+02 Y = 0.00000E+00
 ---------------------------------------------------------------------------
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Time (years)	Flux (mg or Ci/y)	Conc Mbr 1 (mg or Ci per cubic meter)	Conc Mbr 2	Conc Mbr 3	Conc Mbr 4	Conc Mbr 5
2.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
3.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
4.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
5.5000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
7.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
8.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
9.0000E+02	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.0000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.1000E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.3500E+03	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.5000E+03	2.265E-25	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.6500E+03	4.137E-23	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.8000E+03	3.053E-21	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
1.9500E+03	1.159E-19	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.1000E+03	2.611E-18	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.2500E+03	3.872E-17	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.4000E+03	4.089E-16	0.000E+00	0.000E+00	0.000E+00	0.000E+00	0.000E+00
2.5500E+03	3.265E-15	1.504E-20	1.085E-22	2.047E-26	2.909E-26	1.133E-28
2.7000E+03	2.064E-14	9.644E-20	7.368E-22	1.471E-25	2.183E-25	8.520E-28
2.8500E+03	1.072E-13	5.069E-19	4.088E-21	8.609E-25	1.331E-24	5.203E-27
3.2000E+03	2.723E-12	1.317E-17	1.192E-19	2.816E-23	4.739E-23	1.859E-25
3.4000E+03	1.276E-11	6.230E-17	5.989E-19	1.503E-22	2.640E-22	1.038E-24
3.6000E+03	5.014E-11	2.470E-16	2.513E-18	6.672E-22	1.220E-21	4.803E-24
3.8000E+03	1.700E-10	8.434E-16	9.055E-18	2.537E-21	4.814E-21	1.898E-23
4.0000E+03	5.086E-10	2.538E-15	2.867E-17	8.451E-21	1.660E-20	6.552E-23
4.2000E+03	1.366E-09	6.851E-15	8.125E-17	2.513E-20	5.099E-20	2.014E-22
4.4000E+03	3.342E-09	1.684E-14	2.092E-16	6.775E-20	1.417E-19	5.602E-22

4.6000E+03	7.542E-09	3.815E-14	4.953E-16	1.676E-19	3.605E-19	1.427E-21
4.8000E+03	1.586E-08	8.049E-14	1.090E-15	3.848E-19	8.498E-19	3.367E-21
5.0000E+03	3.132E-08	1.595E-13	2.249E-15	8.266E-19	1.872E-18	7.421E-21
5.2000E+03	5.854E-08	2.989E-13	4.383E-15	1.674E-18	3.882E-18	1.540E-20
5.4000E+03	1.042E-07	5.333E-13	8.118E-15	3.219E-18	7.631E-18	3.029E-20
5.6000E+03	1.775E-07	9.104E-13	1.437E-14	5.905E-18	1.430E-17	5.679E-20
5.8000E+03	2.907E-07	1.494E-12	2.441E-14	1.039E-17	2.566E-17	1.020E-19
6.2500E+03	7.790E-07	4.019E-12	7.073E-14	3.239E-17	8.338E-17	3.318E-19
6.5000E+03	1.264E-06	6.531E-12	1.195E-13	5.687E-17	1.495E-16	5.953E-19
6.7500E+03	1.971E-06	1.020E-11	1.938E-13	9.570E-17	2.567E-16	1.022E-18
7.0000E+03	2.968E-06	1.538E-11	3.029E-13	1.551E-16	4.237E-16	1.689E-18
7.2500E+03	4.331E-06	2.248E-11	4.582E-13	2.428E-16	6.753E-16	2.693E-18
7.5000E+03	6.144E-06	3.192E-11	6.730E-13	3.687E-16	1.043E-15	4.159E-18
7.7500E+03	8.497E-06	4.419E-11	9.623E-13	5.444E-16	1.564E-15	6.242E-18
8.0000E+03	1.148E-05	5.977E-11	1.343E-12	7.838E-16	2.286E-15	9.127E-18
8.2500E+03	1.519E-05	7.915E-11	1.833E-12	1.103E-15	3.263E-15	1.303E-17
8.5000E+03	1.972E-05	1.028E-10	2.453E-12	1.519E-15	4.557E-15	1.820E-17
8.7500E+03	2.515E-05	1.312E-10	3.222E-12	2.053E-15	6.238E-15	2.492E-17
9.0000E+03	3.157E-05	1.649E-10	4.161E-12	2.725E-15	8.384E-15	3.351E-17
9.2500E+03	3.905E-05	2.040E-10	5.292E-12	3.560E-15	1.108E-14	4.430E-17
9.5000E+03	4.766E-05	2.491E-10	6.633E-12	4.580E-15	1.442E-14	5.765E-17
9.7500E+03	5.744E-05	3.004E-10	8.206E-12	5.811E-15	1.849E-14	7.396E-17
1.0000E+04	6.843E-05	3.581E-10	1.003E-11	7.279E-15	2.340E-14	9.362E-17
1.0250E+04	8.066E-05	4.222E-10	1.212E-11	9.010E-15	2.925E-14	1.171E-16
1.1000E+04	1.248E-04	6.543E-10	2.013E-11	1.603E-14	5.349E-14	2.141E-16
1.2000E+04	2.004E-04	1.051E-09	3.524E-11	3.054E-14	1.052E-13	4.213E-16
1.3000E+04	2.918E-04	1.532E-09	5.556E-11	5.203E-14	1.841E-13	7.379E-16
1.4000E+04	3.940E-04	2.070E-09	8.073E-11	8.122E-14	2.942E-13	1.180E-15
1.5000E+04	5.013E-04	2.636E-09	1.100E-10	1.183E-13	4.373E-13	1.755E-15
1.6000E+04	6.087E-04	3.202E-09	1.423E-10	1.628E-13	6.131E-13	2.461E-15
1.7000E+04	7.117E-04	3.746E-09	1.766E-10	2.141E-13	8.197E-13	3.291E-15
1.8000E+04	8.074E-04	4.250E-09	2.119E-10	2.714E-13	1.054E-12	4.232E-15
1.9000E+04	8.938E-04	4.706E-09	2.473E-10	3.335E-13	1.312E-12	5.271E-15
2.0000E+04	9.700E-04	5.108E-09	2.821E-10	3.995E-13	1.591E-12	6.391E-15
2.1000E+04	1.036E-03	5.456E-09	3.160E-10	4.687E-13	1.886E-12	7.579E-15
2.2000E+04	1.092E-03	5.752E-09	3.485E-10	5.402E-13	2.196E-12	8.823E-15
2.3000E+04	1.139E-03	6.000E-09	3.795E-10	6.134E-13	2.516E-12	1.011E-14
2.4000E+04	1.178E-03	6.205E-09	4.090E-10	6.881E-13	2.845E-12	1.144E-14
2.5000E+04	1.210E-03	6.373E-09	4.369E-10	7.639E-13	3.183E-12	1.280E-14
2.6000E+04	1.235E-03	6.509E-09	4.634E-10	8.406E-13	3.527E-12	1.418E-14
2.7000E+04	1.256E-03	6.618E-09	4.887E-10	9.182E-13	3.878E-12	1.559E-14
2.8000E+04	1.272E-03	6.706E-09	5.127E-10	9.966E-13	4.235E-12	1.703E-14
2.9000E+04	1.286E-03	6.775E-09	5.357E-10	1.076E-12	4.598E-12	1.849E-14

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Maximum Concentration and Time for Member #1:  6.775E-09  2.900E+04
Maximum Concentration and Time for Member #2:  5.357E-10  2.900E+04
Maximum Concentration and Time for Member #3:  1.076E-12  2.900E+04
Maximum Concentration and Time for Member #4:  4.598E-12  2.900E+04
Maximum Concentration and Time for Member #5:  1.849E-14  2.900E+04
Execution Time (Seconds):   18
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Groundwater Pathway Uncertainty Analysis in Support of the Performance Assessment for the US Ecology Low-Level Radioactive Waste Facility

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Introduction

US Ecology operates a low-level facility on leased land from the U.S. Department of Energy's Hanford Reservation located near Richland Washington. This report documents a parametric uncertainty analysis of the groundwater pathway in support of the low-level waste performance assessment for this facility. Calculations are performed for two cover designs; the site soils alternative cover and an enhanced cover. The site soils cover provides the least amount of protection from infiltrating water and therefore, concentrations are expected to error on the conservative side. The enhanced cover is the most restrictive in terms of limiting percolation, therefore, concentrations are expected to be substantially lower with this cover compared to the site soils cover. Distributions of predicted groundwater concentrations reported in this document will be used in a stochastic all pathway dose assessment to be performed by Washington State Department of Health (WDOH) personnel. The work was funded by WDOH the under contract number N08344.

Methodology and Input Distributions

Deterministic groundwater pathway calculations were originally performed using GWSCREEN Version 2.4a (Rood 1994). Version 2.5 of the code (Rood 1999), which includes several enhancements and the ability to perform Monte Carlo uncertainty analysis, was used to calculate distributions of groundwater concentrations for the uncertainty analysis. The conceptual model for the site soils cover is illustrated in Figure 1. The enhanced cover used a slightly different conceptual model and is described in the Enhanced Cover Methodology section. The disposal area as measured perpendicular to groundwater flow is 518 m by 382 m and 10.6 m deep. Radioactive waste is assumed to be homogeneously mixed with backfilled soil; placed in the disposal trench; and covered by 8 to 11 feet of native soil. Percolating water leaches radionuclides from the disposal trench and they are transported through an 82 m unsaturated zone to an aquifer. Concentrations in the aquifer are then evaluated at a receptor well located on the downgradient edge of the disposal area during the time frame from the present out to 10,000 years.

Model input for the site soils cover is listed in Table 1. Model input for the enhanced cover was basically the same, except infiltration was treated somewhat differently and is discussed in the section on Enhanced Cover Methodology. Radionuclide inventories are provided in Table 2. Nominal values for parameters used in the deterministic runs and distributions assigned to them were provided by WDOH. However, some of the distributions were modified by the author. A discussion of each distribution follows.

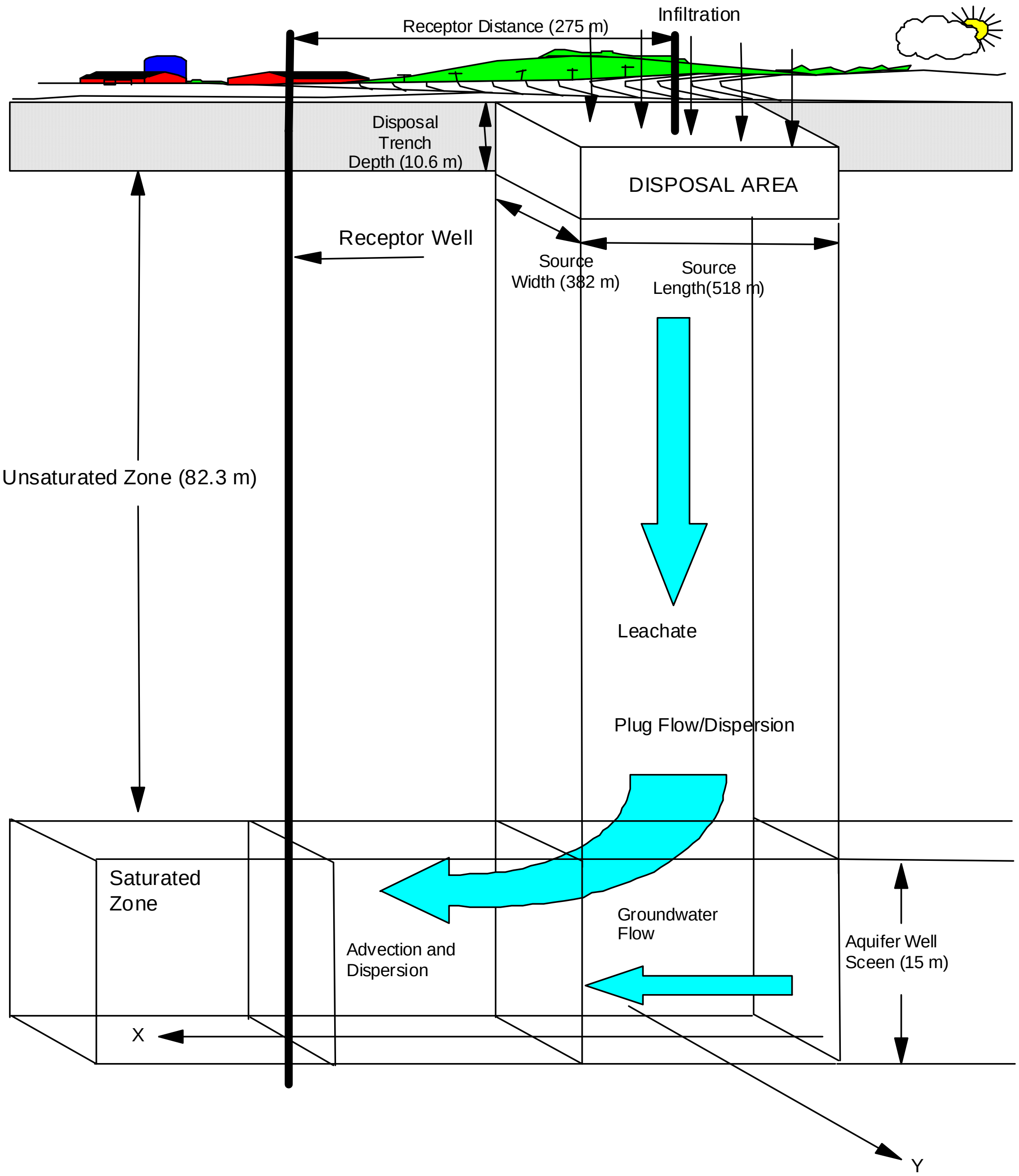

Figure 1. Conceptual model for the release and transport of radionuclides from the disposal trench to the unsaturated and saturated zone.

Table 1. Input Parameters and Distributions for the GWSCREEN Simulations

Parameter Name (GWSCREEN Variable)	Nominal Value	Description and distribution assigned
Length (AL)	518 m	Length of source parallel to groundwater flow, fixed
Width (WA)	382 m	Width of source perpendicular to groundwater flow, fixed
Percolation rate (PERC)[a]	0.02 m y^{-1}	Triangular distribution, minimum = 0.015 m y^{-1}, most likely = 0.02 m y^{-1}, maximum = 0.05 m y^{-1}
Thickness (THICKS)	10.6 m	Thickness of source, fixed
Bulk density of source (RHOS)	1.26 g cm^{-3}	Triangular distribution, minimum=1.008, most likely=1.26, maximum=1.512 g cm^{-3}
Depth to aquifer (DEPTH)	82.3 m	Fixed value
Bulk density of unsaturated zone (RHOU)	1.6 g cm^{-3}	Triangular distribution, minimum=1.52, most likely=1.6, maximum=1.98 g cm^{-3}
Dispersivity in unsaturated zone (AXU)	0.0 m	Truncated normal distribution, mean =4.0 m, standard deviation=2.0 m, minimum=0.0 m, maximum=6.0 m
Longitudinal dispersivity (AX)	27.5 m	Triangular distribution, minimum=13.75 m, most likely=27.5 m, maximum=41.25 m
Transverse dispersivity (AY)	5.0 m	Triangular distribution, minimum=2.5 m, most likely=5.0 m, maximum=7.5 m
Aquifer thickness (B)	15 m	Fixed value
Darcy velocity in aquifer (U)	32.9 m y^{-1}	Truncated lognormal distribution, geometric mean=32.9 m y^{-1}, geometric standard deviation=2.33, minimum=3.0 m y^{-1}, maximum=250 m y^{-1}
Porosity of aquifer	0.1	Triangular distribution, minimum=0.97, most likely=0.1, maximum=0.103
Bulk density of aquifer (RHOA)	1.6 g cm^{-3}	Triangular distribution, minimum=1.52, most likely=1.6, maximum=1.98 g cm^{-3}
Distribution coefficient, Cl (KDS)	0.0 mL g^{-1}	Truncated normal distribution, mean = 0.01 mL g^{-1}, standard deviation = 0.26 mL g^{-1}, minimum = 0.0 mL g^{-1}, maximum = 0.6 mL g^{-1}
Distribution coefficient, I (KDS)	0.3 mL g^{-1}	Truncated lognormal distribution, geometric mean = 0.3 mL g^{-1}, geometric standard deviation = 2.3, minimum = 0.2 mL g^{-1}, maximum = 15 mL g^{-1}
Distribution coefficient, Tc (KDS)	0.0 mL g^{-1}	Truncated normal distribution, mean = 0.01 mL g^{-1}, standard deviation = 0.26 mL g^{-1}, minimum = 0.0 mL g^{-1}, maximum = 0.6 mL g^{-1}
Distribution coefficient, U (KDS)	0.6 mL g^{-1}	Truncated lognormal distribution, geometric mean = 3.0 mL g^{-1}, geometric standard deviation = 3.65, minimum = 0.1 mL g^{-1}, maximum = 79 mL g^{-1}
Distribution coefficient, Th (KDA)	40 mL g^{-1}	Truncated lognormal distribution, geometric mean = 600 mL g^{-1}, geometric standard deviation = 2.1, minimum = 40 mL g^{-1}, maximum = 2000 mL g^{-1}
Distribution coefficient, Ra (KDA)	8 mL g^{-1}	Truncated lognormal distribution, geometric mean = 20 mL g^{-1}, geometric standard deviation = 2.0, minimum = 5 mL g^{-1}, maximum = 173 mL g^{-1}
Distribution coefficient, Pb (KDA)	2000 mL g^{-1}	Uniform distribution; minimum 2000 mL g^{-1}, maximum 6000 mL g^{-1}
Distribution coefficient, Pa (KDA)[b]	0.6 mL g^{-1}	Truncated lognormal distribution, geometric mean = 0.6 mL g^{-1}, geometric standard deviation = 3.65, minimum = 0.01 mL g^{-1}, maximum = 79 mL g^{-1}
Distribution coefficient, Ac (KDA)	100 mL g^{-1}	Truncated lognormal distribution, geometric mean = 100 mL g^{-1}, geometric standard deviation = 1.9, minimum = 60 mL g^{-1}, maximum = 1330 mL g^{-1}
Solubility limit, U (SL)	1 mg L^{-1}	Triangular distribution minimum = 1.0, most likely = 25., maximum = 50.

a) Site soils cover percolation. See text for discussion on moisture contents as related to percolation.. Enhanced cover percolation is discussed in another section.

b) The distribution presented here was for the site soils cover. For the enhanced cover the distribution was described by triangular distribution having a minimum value of 2.4, most likely value of 15, and a maximum value of 22 mL g^{-1}. For the site soils cover, it was necessary to use the Uranium K_d values to preserve correlation during sampling. See text for additional explanation.

Table 2 Radionuclide Inventories used in Performance Assessment

Radionuclide	Inventory (Ci)
Cl-36	4.907
I-129	6.012
Tc-99	67.1
U-238	22,280
U-235	14,680

Percolation Rate and Moisture Content for Site Soils Cover

A range of percolation rates through the waste for the site soils cover were provided by WDOH. This upper bound limiting case assumed conditions where the amount of percolation would increase due to such changes as subsidence or decrease in vegetation. The nominal value of 20 mm y^{-1} was taken as the most likely[1] value that reflected typical background conditions. A triangular distribution then was assigned having a minimum of 15 mm y^{-1} and a maximum of 50 mm y^{-1}.

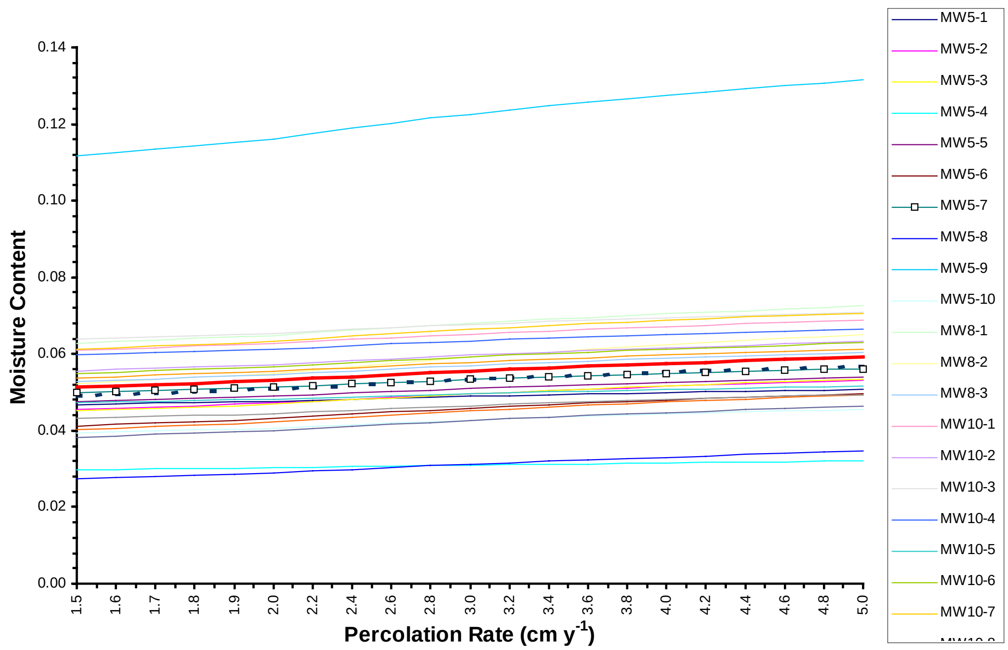

Figure 2. Moisture content, as a function of percolation, for the 22 moisture characteristic curves provided by WDOH Khaleel and Freeman (1995). Van Genuchten fitting parameters also from Khaleel and Freeman (1995).

Moisture content is a function of the percolation rate under unsaturated conditions. GWSCREEN Version 2.5 has the capability to calculate moisture content internally by providing the code with the Van Genuchten fitting parameters for moisture characteristic curves. Moisture characteristic curves for soils

[1] The value which, if exists, occurs most often in a distribution. Also called the mode.

within the Hanford Reservation have been measured and published (Khaleel and Freeman 1995). Twenty-three moisture characteristic curves representing sandy soils at the US Ecology facility were provided by WDOH. Moisture content as a function of percolation was then calculated for all moisture characteristic curves (Figure 2). The Moisture Characteristic curve selected was based on the single curve that gave best fit to the geometric mean of the moisture content versus percolation rate for all the curves (Curve MW5-7 on Figure 2). The geometric mean of the moisture content (considering all curves) varied from 0.049 to 0.057 for percolation rates between 15 and 50 mm y^{-1}. The curve selected had the following Van Genuchten fitting parameters: $\alpha = 7.51\ m^{-1}$, n = 2.298, saturated hydraulic conductivity = 1710 m y^{-1}, total porosity = 0.2724, and residual moisture content = 0.0321. The values for the curve were not selected by any numerical technique that would for example, find the curve that best matched the mean value by computing sum of squares of the residuals. The curve selected was simply “eyeballed” from Figure 2. If the moisture content showed greater variability within the percolation range, then numeric techniques would have been warranted. However, moisture content only varied by 16% between the driest and wettest conditions and a more precise method of estimating the curve would probably have little impact on overall results. The curve is intended to represent the bulk characteristics of the soil at the site. In reality, these characteristics are spatially variable. However, the GWSCREEN model in not capable of incorporating such variability into a simulation.

Uncertainty in the Van Genuchten fitting parameters themselves was not considered. To consider uncertainty in the fitting parameters, confidence intervals around each of the fitting parameters for the 23 curves would have to have been provided. These data were not available. It is not correct to generate distributions of fitting parameters from the 23 curves provided because a) parameters are correlated with one another and b) the 23 curves represent natural variability and not uncertainty.

Bulk Densities

Nominal values for the bulk density were provided by WDOH. These values were assumed to vary by ± 20%. The nominal value for the source was 1.26 g cm^{-3} and 1.6 g cm^{-3} for the unsaturated zone and aquifer. Twenty-percent of the nominal value was 0.252 g cm^{-3} for the source and 0.32 g cm^{-3} for the unsaturated zone and aquifer. A triangular distribution was assigned having a most likely value equivalent to the nominal value, a minimum value equal to the nominal value minus 20% of the nominal value, and a maximum value equal to the nominal value plus 20% of the nominal value.

Dispersivity

Nominal values for longitudinal and transverse dispersivity in the aquifer were provided by WDOH. These values were assumed to vary by ± 50%. The nominal value for the longitudinal dispersivity was 27.5 m and 5 m for the transverse dispersivity. Fifty-percent of the nominal value was 13.75 m for the longitudinal dispersivity and 2.5 m for the transverse dispersivity. A triangular distribution was assigned having a most likely value equivalent to the nominal value, a minimum value equal to the nominal value minus 50% of the nominal value, and a maximum value equal to the nominal value plus 50% of the nominal value.

Dispersivity in the unsaturated zone was not provided by WDOH and the nominal value and distribution was assigned by the author. Deterministic calculations were performed using a version of GWSCREEN (version 2.4a) that assumed plug flow (no dispersion). Therefore, by default, zero dispersivity was assumed in the deterministic case. A value for the longitudinal dispersivity was calculated using the equations developed by Xu and Eckstein (1995) and reported in the GWSCREEN Version 2.5 user's manual (Rood 1999). The longitudinal dispersivity (α_L) is given by

$$\alpha_L = 0.83\left(\log_{10} L\right)^{2.414} \tag{1}$$

where L is the length of the domain in the longitudinal direction and equivalent to the depth to the aquifer. Using the depth to the aquifer of 82.3 m, Equation 1 gives an estimate of the longitudinal dispersivity of ~4 m. The dispersivity was assumed to be normally distributed, having a mean of 4 m and have a standard deviation of 2 m. This gives roughly an upper bound α_L value of 8 m and a lower bound of zero. For conservatism the distribution was truncated on the upper end at 6.0 m because the greater the dispersivity, the lower the peak concentration. On the lower end, the minimum value of the distribution was truncated by 0.0 m because negative dispersivity is not plausible.

Darcy Velocity and Porosity

Originally, data was provided for this parameter in the form of the average linear velocity as required by GWSCREEN version 2.4a. The average linear velocity is the Darcy velocity divided by the porosity. In GWSCREEN version 2.5, the Darcy velocity is input. The Darcy velocity can be approximated by Darcy's Law, which states:

$$v = K_{sat} \frac{dh}{dL} \tag{2}$$

where
v = the Darcy velocity (m y^{-1}),
K_{sat}= the saturated hydraulic conductivity (m y^{-1}),
dh/dx= the hydraulic gradient (m m^{-1}).

A range of 0.04 to 8.0 m d^{-1} (14.6 to 2920 m y^{-1}) was provided by WDOH for the average linear velocity with a median[2] value of 0.9 m d^{-1} (329 m y^{-1}). These data were based on a range of saturated hydraulic conductivities from 730–73,000 m y^{-1} (Connelly, M.P et al, 1992) and hydraulic gradients that range from 0.002 to 0.004 (Cole et al, 1997). The hydraulic gradient data was based on projections for the year 2350 by which time there will no longer be mounding of the water table due to injection practices upgradient. The median value for saturated hydraulic conductivity was 10,950 m y^{-1}. The distribution assigned to the Darcy velocity was generated by assuming a lognormal distribution for saturated hydraulic conductivity and a triangular distribution for hydraulic gradient. The median value for the saturated hydraulic conductivity was taken to represent the geometric mean, and a geometric standard deviation was fit such that the 1% and 99% value was near that of the given range. A value of 2.4 was the best fit. The midpoint in range of hydraulic gradient was taken to be the most likely value of a triangular distribution (0.003) with a minimum and maximum value of 0.002 and 0.004 respectively. Sampling was performed using the Crystal Ball® software (Decisioneering 1996). The output distribution had a geometric mean of 32.9 m y^{-1} and a geometric standard deviation of 2.33. The distribution was truncated by the minimum (14.6 m y^{-1}) and maximum (2920 m y^{-1}) values because

[2] The value midway (in terms of order) between the smallest and the largest possible value in a distribution

these are the minimum and maximum Darcy velocity values calculated using the range of saturated hydraulic conductivity (730–73,000 m y^{-1}) and hydraulic gradient (0.002 to 0.004).

The distribution assigned to the porosity in the aquifer was provided by WDOH. A nominal value of 0.1 was given and reported to vary by ± 3% (Cole et al. 1997). A triangular distribution was assigned having a most likely value of 0.1 and a minimum of 0.97 and maximum of 0.103.

Distribution Coefficients and Solubility

Distribution coefficients (K_d) were derived from Kincaid et al. (1998) who obtained K_d values from the literature and site-specific measurements. These distribution coefficients were used in the U.S. DOE composite performance assessment for the 200 Areas on the Hanford Reservation (Kincaid et al. (1998)). These data included a recommended conservative value, "best estimate" value, and a range. In general, the "best estimate" value was used to represent either the median or most likely value. The type of distribution assigned was then based on the range of values. Three distributions were used: truncated lognormal, triangular, and truncated normal. If the range between the minimum and maximum values exceeded an order of magnitude, then truncated lognormal distributions were assigned. Triangular distributions were assigned to distribution coefficients if the range between minimum and maximum values was less than an order of magnitude. Truncated normal distributions were assigned if the distribution coefficient value included 0 in its range. Truncated normal distributions were assigned to Cl-36 and Tc-99.

Because GWSCREEN assumes correlation between parent and progeny of the same element, the first significant daughter of U-238 (U-234) is not sampled and assumes the distribution coefficients sampled for U-238. Therefore, the first daughter for all the other nuclides had to have identical distribution coefficients to that of their parent. This only made a difference in the case of U-235, the only other nuclide with daughter products in this analysis. In order to keep the same random number sequence, Pa-231 (the first significant daughter) was assigned a distribution coefficient distribution identical to that of its parent. For the enhanced cover, a different procedure was used for the Monte Carlo analysis and it was not necessary to set the Pa-231 K_d to the uranium K_d. Therefore, for the enhanced cover, the Pa-231 K_d was assigned a distribution using data from Kincaid et al. (1998).

At the direction of WDOH, solubility limited releases for I, Cl, and Tc were not to be considered. Therefore a solubility limit of 1×10^6 mg L^{-1} was used for these elements which essentially disables consideration of a solubility release. In any case, there was insufficient mass of these elements such that solubility would become an issue.

Distributions of uranium solubility provided by WDOH were based on data in DOE 1994. Uranium is classified as moderately soluble and given a best estimate value of 25 mg L^{-1}. Unpublished work done at Hanford indicates uranium solubility maybe as low as 1 mg L^{-1} (oral communication with R. J. Serne 1999 and Serne et al. 1999). This value was assumed to be the lower bound of a triangular distribution. A most likely and maximum value of 25 mg L^{-1} and 50 mg L^{-1} respectively were then assigned to the distribution.

Methodology Modifications for the Enhanced Cover

The conceptual model for the enhanced cover (Figure 3) assumes the emplacement of a cover restricts water flow through the waste but does not restrict water movement in the unsaturated zone underlying the waste. Under these conditions, radionuclides leaching from the waste are governed by infiltration through the cover, but their movement through the unsaturated zone to the aquifer is not. That is, radionuclides move at the same rate through the unsaturated zone as if no cover was in place.

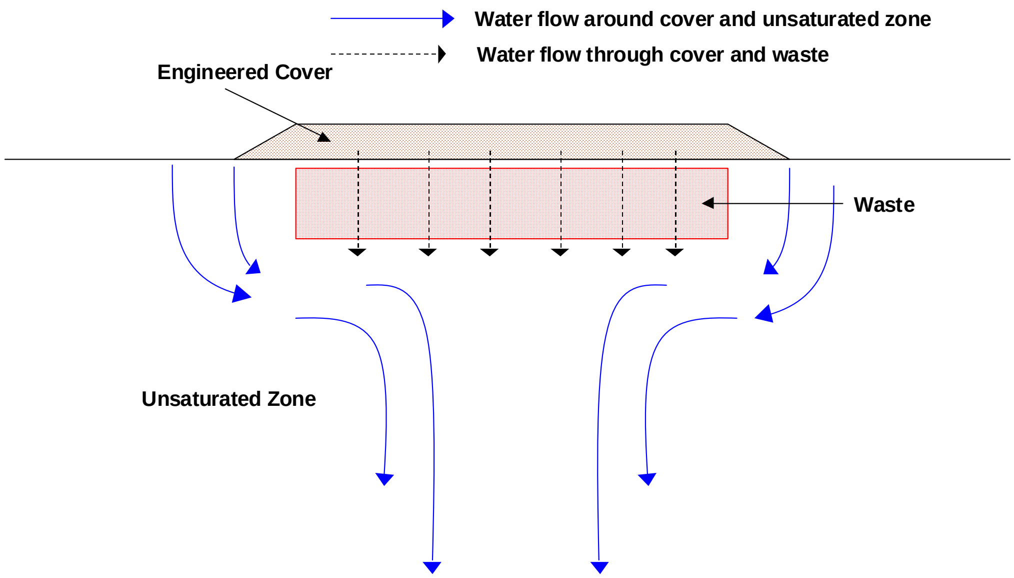

Figure 3. Conceptual model for water flow around and through an engineered cover.

In reality, the placement of an engineered cover will certainly create an "infiltration shadow" underneath the disposal site. At depth, water infiltrating from outside the cover will migrate horizontally and eventually mix with the vertical flow of water that travelled through the cover and the waste. The vertical extent of the shadow is not known but could be estimated using additional model calculations or field studies. The conceptual model described here conservatively assumes the shadow is minimal in vertical extent. Therefore, in this conceptual model, the engineered cover only has the effect of reducing the mass flux of radionuclides through the waste and does not affect transit times in the unsaturated zone. Water fluxes in the unsaturated zone are therefore equivalent to the background percolation rate from natural recharge estimated to be 5 mm y^{-1} (Kincaid et al, 1998; Wood et al, 1996).

Mathematical Model and Implementation

The GWSCREEN Version 2.5 conceptual model (Rood 1999a) does not allow for different Darcy velocities in the source and unsaturated zone. Therefore, some modifications of the input were necessary to implement the "no shadow effect" on transport of radionuclides in the unsaturated zone. The Darcy velocity in the unsaturated zone only affects the mean transit time in the unsaturated zone. While the concentrations of the leachate may change with changes in the Darcy velocity, this effect makes no difference in the aquifer model because the aquifer model uses only the mass flux from the unsaturated zone and not the leachate concentration.

Given that changes in the Darcy velocity in the unsaturated zone affects only the mean unsaturated transit time, then our goal is to adjust the transport parameters such that the water transit time reflects natural percolation and not infiltration through the site cover. The mean unsaturated transit time is given by

$$t = \frac{x\theta}{v} R_d \tag{3}$$

where

x	=	unsaturated thickness (m)
θ	=	moisture content in unsaturated zone
v	=	Darcy velocity in unsaturated zone (m y^{-1})
R_d	=	retardation factor (nuclide specific, unit less)
t	=	mean unsaturated transit time (y).

We want to adjust one of the parameters in Equation 1 so that t is equivalent to the mean unsaturated transit time for background infiltration. Because we want to use a Darcy velocity for the waste that reflects infiltration through the cap, and we cannot change that velocity for the unsaturated zone (using the surface or buried source model), then the logical parameter to adjust is the unsaturated thickness. Solving Equation 1 for x and substituting t_{blk} for t, θ_{bkg} for θ, and v_{cover} for v, gives the unsaturated thickness to use in the simulation for a specific cover.

$$x = \frac{t_{bkg}\, v_{\mathrm{cov}\,er}}{\theta_{b\,\mathrm{lg}}\, R_d} \tag{4}$$

where:

x	=	unsaturated thickness to use in the simulation for a specific cover (m)
θ_{bkg}	=	moisture content in unsaturated zone for background infiltration
v_{cover}	=	Darcy velocity through the cover (m y^{-1})
t_{bkg}	=	mean unsaturated transit time for background infiltration (y).

Mean unsaturated transit time for background infiltration was 752 y for a non-sorbing radionuclide ($K_d = 0$; $R_d = 1$) and is based on 0.005 m y^{-1} infiltration, 82.3 m unsaturated thickness, and 0.0457 moisture content.

GWSCREEN Version 2.5 allows for dispersion in the unsaturated zone and therefore, the unsaturated dispersivity must also be adjusted. To simulate the same dispersion effects for different unsaturated thickness given a stochastic unsaturated dispersivity, the Peclet number is kept constant for each simulation. The Peclet number relates the ratio of advection to dispersion and is given by

$$Pe = \frac{x}{\alpha_L} \tag{5}$$

where α_L = the longitudinal dispersivity (m). If the Peclet number is determined first for an unsaturated thickness of 82.3 m and a given value of α_L, then an *effective* dispersivity can be calculated for a different unsaturated thickness such that the relative effect of dispersivity is preserved. The method was tested by calculating the radionuclide flux as a function of time from the disposal facility for the enhanced cover. The flux was then put into GWSCREEN as a user-defined source, the percolation rate was set at background (5 mm y–1), and the unsaturated thickness was set at the nominal value of 82.3 m. The testing method just described could have also been used to calculate groundwater concentrations for the stated conditions. It is more explicit than the method described by Equation 3–5, but also more laborious to implement. Both methods gave identical results.

The distribution of percolation rates was provided by WDOH. Three values were provided: a minimum (0.01 mm y^{-1}), a most likely (0.5 mm y^{-1}), and a maximum (10 mm y^{-1}). The weight of the distribution was to fall in the 0.5 to 3 mm y^{-1}. Given these data, a custom distribution was constructed in Crystal Ball (Figure 4).

Implementation of the stochastic analysis for the enhanced cover required writing an external program because the Monte Carlo sampling features of GWSCREEN could not be used. A script file written in the Perl programming language (Attachment A) was used to (1) read sequentially from an external file, a parameter value for each realization, (2) calculate a new unsaturated thickness and dispersivity as described by equations 3 through 5, (3) write a GWSCREEN input file and execute GWSCREEN, and (4) extract results (concentrations) from the output file and store. Except for the percolation rate and Pa-231 K_d, all other parameter distributions were identical to that used in the site soils cover analysis.

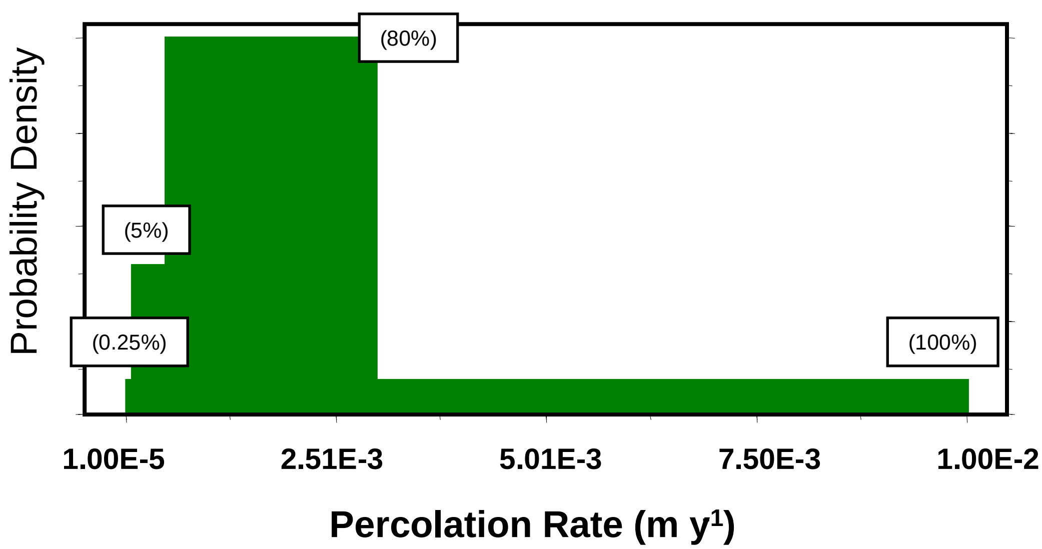

Figure 4. Probability density function for enhanced cover percolation rate. Cumulative probability at each of the inflection points is indicated by the percentage value in the box.

Results for the Site Soils Cover

Two types of analysis were run. The first calculated the peak concentration and time of peak concentration for all 5 nuclides. These results are summarized in Figures 5–9 which show the relationship between peak concentration and peak time. The peak time is the time at which the peak concentration in the aquifer occurred at the receptor well. In general, we see a decrease in the peak concentration with increasing peak time. This trend is probably a reflection of the percolation rate and the distribution coefficient. Higher percolation rates result in higher contaminant fluxes to the groundwater and shorter contaminant travel times resulting in higher aquifer concentrations. The distribution coefficient is inversely related to the peak concentration. The distribution coefficient is inversely related to the peak concentration. Higher distribution coefficients translate into more mass in the solid phrase which results in lower pore water concentrations and longer contaminant travel times.

The deterministic values shown in Figures 5–9 are the peak concentrations generated using the nominal parameter values listed in Table 1. For Cl-36, I-129, and Tc-99, the deterministic value is on the high-end of the distribution of peak concentrations (i.e., relatively high peak concentrations). For the uranium isotopes, the deterministic value is on the lower end of the distribution of peak concentrations (i.e., relatively low peak concentrations). The difference between the fission/activation products (Cl-36, I-129, Tc-99) and the uranium isotopes is believed to be due to choice of the nominal distribution coefficients and solubility limits respectively. For the fission/activation products, the nominal values chosen for the distribution coefficients were the smallest values (more conservative) in the distribution. Consequently, high peak concentrations were calculated for the fission/activation product deterministic runs. For the uranium isotopes, solubility controls the release and the value chosen as the nominal value (1 mg L^{-1}) was on the low-end (less conservative) of the distribution. In the case where solubility controls the release, pore water concentration in the source is directly related to the solubility limit. Consequently, aquifer concentrations are also lower because lower pore water concentrations in the source result in lower contaminant fluxes to the groundwater.

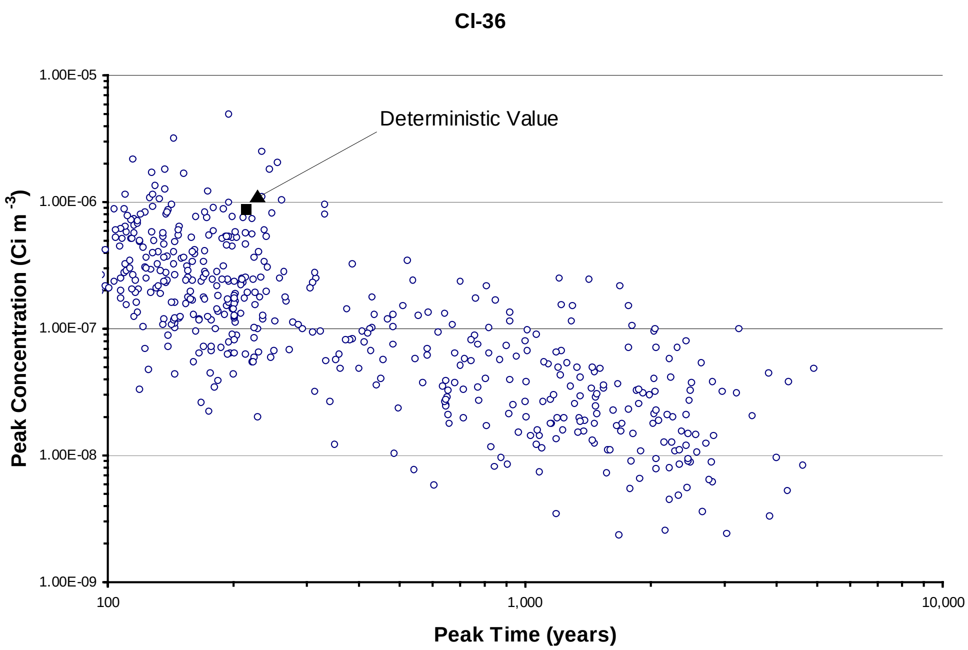

Figure 5. Peak concentration in the aquifer at the receptor well as a function of the time of peak concentration (peak time) for Cl-36. Deterministic value shown was the peak concentration generated using the nominal parameter values listed in Table 1.

As stated earlier, the solubility limit controlled many of the releases for uranium isotopes. Solubility limited releases result in a flat concentration versus time curves. Figure 10 shows the concentration versus time curve for U-238 using the nominal values. Note that the concentration is the same (7.0×10^{-9} Ci m^{-3}) from year 4180 to year 16,721,680. The peak finding routine in GWSCREEN when the solubility limit controls the release locates the peak time anywhere within the flat portion of the curve. Therefore, the time of peak concentration in Figures 8 and 9 for uranium isotopes could have occurred earlier or later than shown including earlier than 10,000 years.

For Cl-36 and Tc-99, peak concentrations occurred between 100 and 10,000 years in all cases. Iodine-129 peaked for the most part between 1,000 and 10,000 years, however some peaks occurred after 10,000 years.

Concentrations of uranium progeny were not shown in Figures 8 and 9. In general, progeny were found to be of little importance because little ingrowth occurs during the 10,000 year time frame (see Table 4 and discussion in next paragraph).

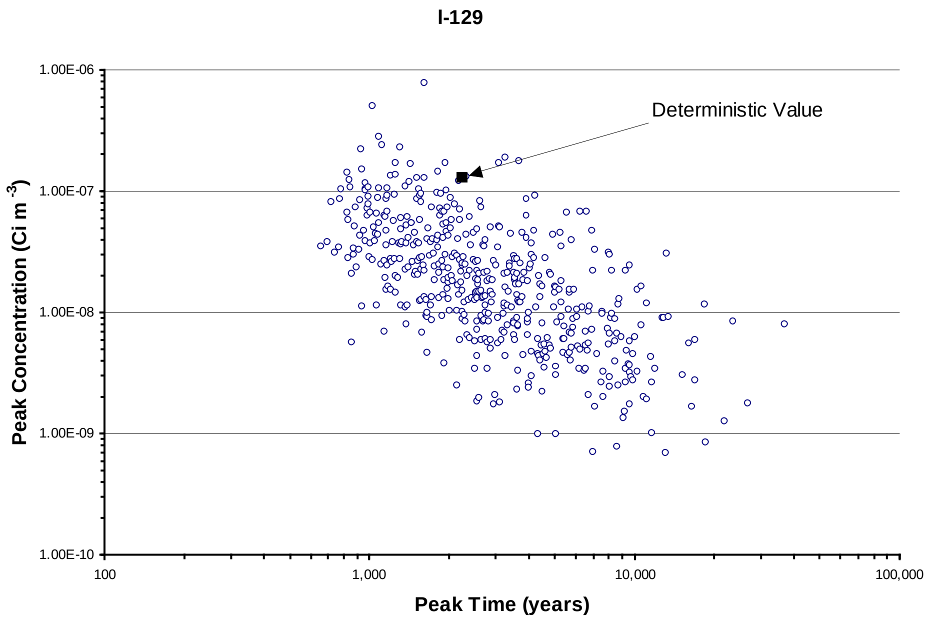

Figure 6. Peak concentration in the aquifer at the receptor well as a function of the time of peak concentration (peak time) for I-129. Deterministic value shown was the peak concentration generated using the nominal parameter values listed in Table 1.

The second analysis involved calculating the concentration of all nuclides at selected points in time. Based on the results of the first analysis, the following times were selected: 200, 300, 400, 500, 900, 1,000, 1,100, 1,500, 2,000, 2,500, 5,000, and 10,000 years. These times were selected on the basis of the results shown in Figures 5–9 and were intended to bracket the maximum concentration observed for all nuclides. Recall that for the uranium isotopes, the concentration versus time curve was flat because the solubility limit controls the release. Therefore, the concentration obtained at say, year 5,000 would be the same as obtained at year 10,000.

Each of the 500 realizations[3] was saved in a Excel™ spreadsheet (TIMECONC.XLS). It is important to sample directly from the realizations when performing the stochastic all pathway dose assessment because each realization for a given nuclide is correlated with the corresponding realization of the other nuclides. These correlations are present in the water flow and transport parameters (percolation rate, moisture content, bulk density, porosity, unsaturated and saturated dispersivity, and Darcy velocity). Uncorrelated parameters are the distribution coefficients and solubility limits. The spreadsheet also contains the sampled values for each parameter. These values are summarized in Table 3. Table 4 contains the maximum and mean concentrations from the 500 GWSCREEN realizations for each nuclide at selected output times. Note that the uranium progeny concentrations are typically lower than their

[3] In a later calculation, number of realizations was increased to 1000. Results were put into the spreadsheet, TIMECONC1000.XLS.

parent concentrations by an order of magnitude or more. Therefore, dose contributions from radioactive progeny are not anticipated to be significant.

Attachment B contains the GWSCREEN input and output files. Output files are presented for runs using the nominal input values. Please refer to the Excel spreadsheet, TIMECONC.XLS, for output from all 500 realizations.

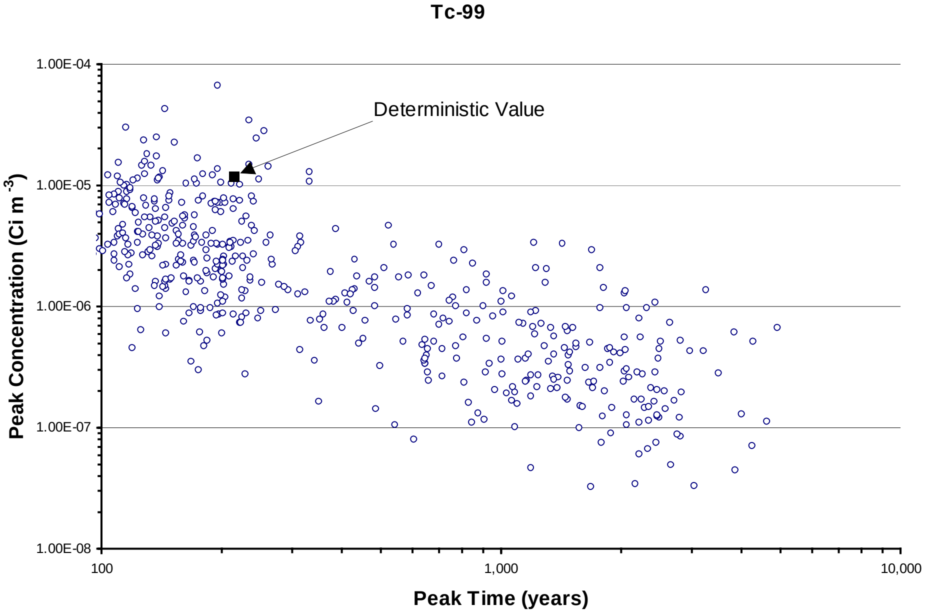

Figure 7. Peak concentration as a function of the time of peak concentration (peak time) for Tc-99. Deterministic value shown was the peak concentration generated using the nominal parameter values listed in Table 1.

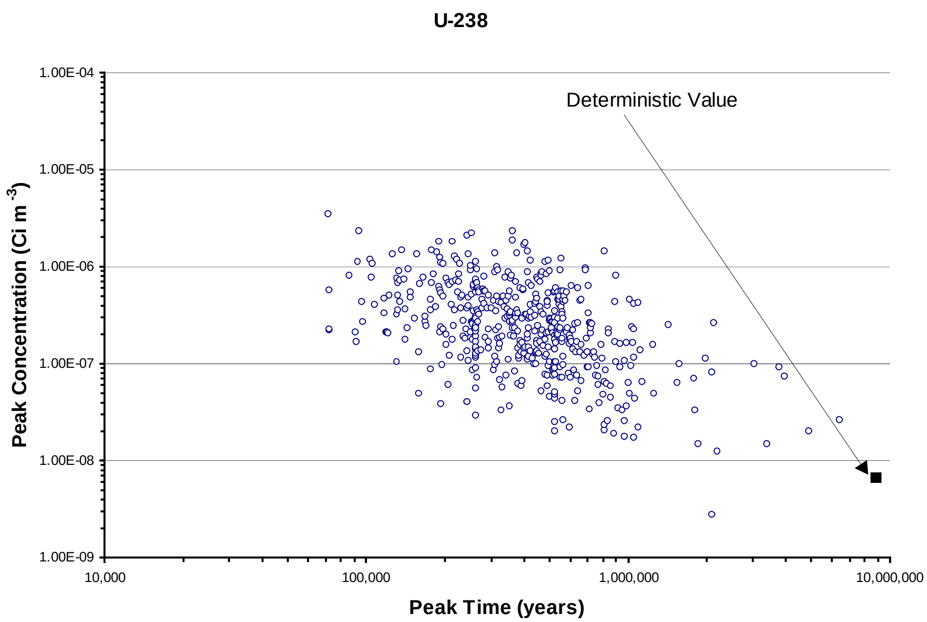

Figure 8. Peak concentration as a function of the time of peak concentration (peak time) for U-238. Deterministic value shown was the peak concentration generated using the nominal parameter values listed in Table 1.

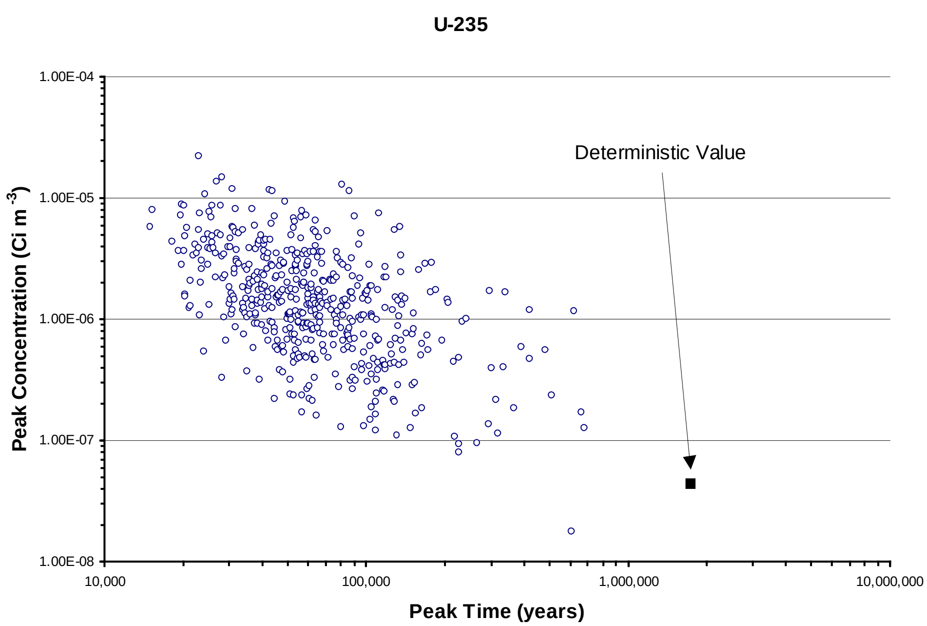

Figure 9. Peak concentration as a function of the time of peak concentration (peak time) for U-235. Deterministic value shown was the peak concentration generated using the nominal parameter values listed in Table 1.

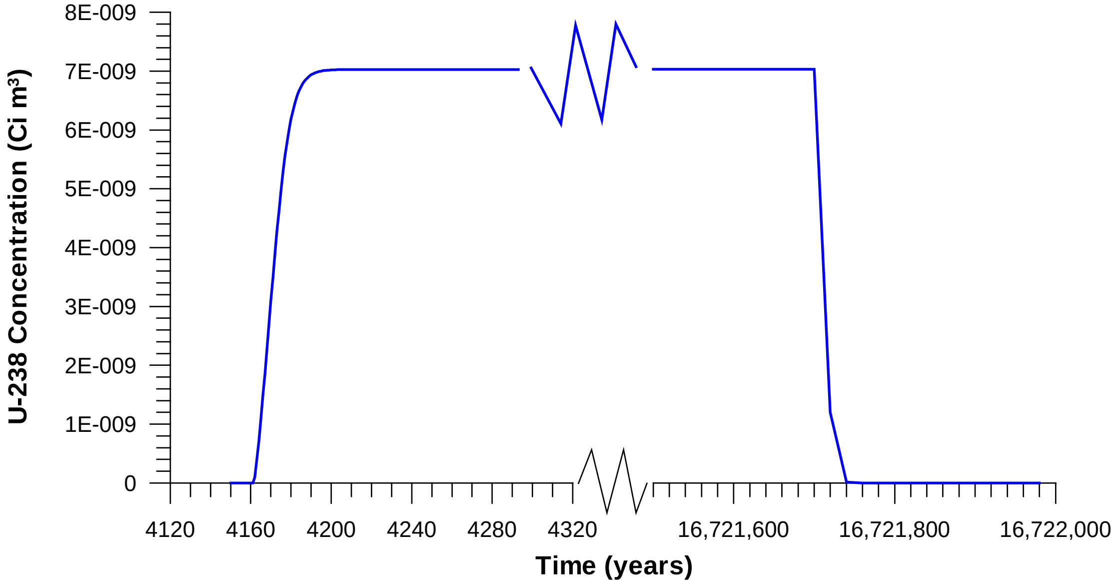

Figure 10. Uranium-238 concentration as a function of time. Values were generated using the nominal values for U-238 listed in Table1. Concentrations between the years 4320 and 16,721,500 are not shown. The concentration remained the same during those years.

Table 3. Summary of the Sampled Parameters for 500 Realizations of GWSCREEN.

Parameters	Min	Max	Mean	Median
PERC (m y^{-1})	1.54E-02	4.88E-02	2.86E-02	2.71E-02
AX (m)	1.39E+01	4.05E+01	2.75E+01	2.75E+01
AY (m)	2.60E+00	7.34E+00	5.01E+00	5.03E+00
AXU (m)	0.00E+00	6.00E+00	3.80E+00	3.84E+00
U (m y^{-1})	3.27E+00	2.50E+02	4.75E+01	3.17E+01
RHOS (g cm^{-3})	1.02E+00	1.50E+00	1.26E+00	1.27E+00
RHOU (g cm^{-3})	1.53E+00	1.96E+00	1.70E+00	1.68E+00
RHOA (g cm^{-3})	1.54E+00	1.97E+00	1.70E+00	1.68E+00
PORS	9.72E-02	1.03E-01	1.00E-01	1.00E-01
CL K_d (mL g^{-1})	0.00E+00	6.00E-01	9.57E-02	0.00E+00
I K_d (mL g^{-1})	2.00E-01	4.94E+00	6.70E-01	4.82E-01
Tc K_d (mL g^{-1})	0.00E+00	6.00E-01	9.57E-02	0.00E+00
U K_d (mL g^{-1})	1.00E-01	7.93E+01	6.06E+00	2.83E+00
Th K_d (mL g^{-1})	5.54E+01	2.00E+03	7.48E+02	6.01E+02
Ra K_d (mL g^{-1})	5.00E+00	1.43E+02	2.72E+01	2.12E+01
Pb K_d (mL g^{-1})	2.00E+03	6.00E+03	4.00E+03	3.91E+03
Pa K_d (mL g^{-1})	1.00E-01	2.00E+01	1.26E+00	6.25E-01
Ac K_d (mL g^{-1})	6.00E+01	6.29E+02	1.28E+02	1.00E+02
Sol U (mg L^{-1})	1.98E+00	4.93E+01	2.49E+01	2.45E+01

Table 4. Maximum and Mean Concentration from the 500 GWSCREEN Realizations at Selected Output Times for the Site Soils Cover

	Time (Years)	Cl-36 (Ci/m^3)	I-129 (Ci/m^3)	Tc-99 (Ci/m^3)	U-238 (Ci/m^3)	U-234 (Ci/m^3)	Th-230 (Ci/m^3)	Ra-226 (Ci/m^3)	Pb-210 (Ci/m^3)	U-235 (Ci/m^3)	Pa-231 (Ci/m^3)	Ac-227 (Ci/m^3)
Maximum	200	1.E-06	2.E-10	2.E-05	7.E-10	4.E-13	4.E-20	4.E-20	3.E-22	5.E-09	2.E-11	1.E-14
	300	1.E-06	8.E-09	2.E-05	6.E-08	5.E-11	8.E-18	1.E-17	1.E-19	4.E-07	3.E-09	2.E-12
	400	7.E-07	4.E-08	1.E-05	4.E-07	4.E-10	1.E-16	2.E-16	1.E-18	2.E-06	2.E-08	1.E-11
	500	3.E-07	8.E-08	3.E-06	7.E-07	1.E-09	6.E-16	7.E-16	6.E-18	5.E-06	5.E-08	3.E-11
	900	4.E-07	1.E-07	5.E-06	1.E-06	3.E-09	7.E-15	1.E-14	5.E-17	7.E-06	1.E-07	2.E-10
	1000	5.E-07	1.E-07	7.E-06	1.E-06	3.E-09	9.E-15	2.E-14	7.E-17	7.E-06	2.E-07	2.E-10
	1100	3.E-07	1.E-07	4.E-06	1.E-06	4.E-09	1.E-14	3.E-14	1.E-16	7.E-06	2.E-07	2.E-10
	1500	1.E-07	2.E-07	2.E-06	1.E-06	5.E-09	2.E-14	9.E-14	2.E-16	7.E-06	2.E-07	4.E-10
	2000	1.E-07	1.E-07	1.E-06	1.E-06	6.E-09	5.E-14	2.E-13	1.E-15	7.E-06	3.E-07	1.E-09
	2500	1.E-07	2.E-07	1.E-06	1.E-06	8.E-09	1.E-13	6.E-13	4.E-15	7.E-06	4.E-07	3.E-09
	5000	2.E-08	8.E-08	3.E-07	1.E-06	2.E-08	7.E-13	2.E-11	4.E-14	7.E-06	7.E-07	8.E-09
	10000	1.E-10	2.E-08	1.E-09	2.E-06	4.E-08	1.E-11	5.E-10	1.E-12	1.E-05	2.E-06	6.E-08
Mean	200	1.E-07	4.E-13	1.E-06	2.E-12	9.E-16	1.E-22	1.E-22	6.E-25	1.E-11	4.E-14	3.E-17
	300	4.E-08	2.E-11	6.E-07	1.E-10	1.E-13	3.E-20	4.E-20	2.E-22	1.E-09	6.E-12	5.E-15
	400	2.E-08	2.E-10	2.E-07	1.E-09	1.E-12	4.E-19	6.E-19	4.E-21	6.E-09	5.E-11	5.E-14
	500	1.E-08	7.E-10	2.E-07	2.E-09	3.E-12	2.E-18	3.E-18	2.E-20	1.E-08	2.E-10	2.E-13
	900	1.E-08	6.E-09	1.E-07	7.E-09	2.E-11	3.E-17	8.E-17	4.E-19	5.E-08	9.E-10	1.E-12
	1000	1.E-08	8.E-09	1.E-07	8.E-09	2.E-11	5.E-17	1.E-16	6.E-19	5.E-08	1.E-09	2.E-12
	1100	9.E-09	9.E-09	1.E-07	9.E-09	3.E-11	7.E-17	2.E-16	9.E-19	6.E-08	1.E-09	3.E-12
	1500	5.E-09	1.E-08	7.E-08	1.E-08	5.E-11	2.E-16	9.E-16	4.E-18	8.E-08	2.E-09	6.E-12
	2000	3.E-09	1.E-08	5.E-08	2.E-08	1.E-10	7.E-16	4.E-15	2.E-17	1.E-07	5.E-09	2.E-11
	2500	2.E-09	1.E-08	3.E-08	2.E-08	2.E-10	2.E-15	1.E-14	6.E-17	2.E-07	8.E-09	4.E-11
	5000	3.E-10	4.E-09	4.E-09	6.E-08	8.E-10	3.E-14	4.E-13	2.E-15	4.E-07	4.E-08	3.E-10
	10000	5.E-13	7.E-10	7.E-12	1.E-07	4.E-09	5.E-13	8.E-12	4.E-14	8.E-07	2.E-07	2.E-09

Results for the Enhanced Cover

For the enhanced cover simulation, a single analysis was performed where concentrations were output at specific times and saved in a Microsoft Excel™ spreadsheet (CONCENTRATION.XLS). A summary of these data are presented in Table 5 for the 5th, 50th, and 95th percentiles. Concentrations were substantially lower compared to those for the site soils cover. Concentrations were lower because; a) decreased leaching from the waste trench due to lower percolation through the waste, and b) longer water travel times in the unsaturated zone delayed the arrival of I-129, U-238 and U-235.

Table 5. Percentiles of Concentration from 1000 GWSCREEN Realizations at Selected Output Times for the Enhanced Cover

Percentile	Time (years)	Cl-36 (Ci m^{-3})	I-129 (Ci m^{-3})	Tc-99 (Ci m^{-3})	U-238 (Ci m^{-3})	U-234 (Ci m^{-3})	Th-230 (Ci m^{-3})	Ra-226 (Ci m^{-3})	Pb-210 (Ci m^{-3})	U-235 (Ci m^{-3})	Pa-231 (Ci m^{-3})	Ac-227 (Ci m^{-3})
5%	400	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	500	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	600	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	700	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	800	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	900	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1000	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1100	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1500	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	2000	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	2500	3.E-20	0.E+00	4.E-19	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	5000	2.E-19	0.E+00	2.E-18	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	10000	1.E-34	0.E+00	2.E-33	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
50%	400	6.E-12	0.E+00	8.E-11	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	500	3.E-10	0.E+00	4.E-09	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	600	2.E-09	0.E+00	2.E-08	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	700	4.E-09	0.E+00	5.E-08	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	800	6.E-09	0.E+00	9.E-08	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	900	7.E-09	0.E+00	1.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1000	8.E-09	0.E+00	1.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1100	7.E-09	0.E+00	9.E-08	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1500	3.E-09	0.E+00	4.E-08	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	2000	6.E-10	0.E+00	9.E-09	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	2500	2.E-10	8.E-20	2.E-09	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	5000	7.E-12	9.E-13	9.E-11	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	10000	2.E-14	5.E-10	2.E-13	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
95%	400	7.E-09	0.E+00	1.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	500	3.E-08	0.E+00	3.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	600	5.E-08	0.E+00	7.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	700	8.E-08	0.E+00	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	800	1.E-07	0.E+00	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	900	1.E-07	3.E-19	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1000	9.E-08	6.E-18	1.E-06	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1100	7.E-08	6.E-17	9.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	1500	3.E-08	4.E-14	4.E-07	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00	0.E+00
	2000	2.E-08	3.E-12	2.E-07	5.E-23	3.E-25	1.E-30	2.E-29	5.E-32	2.E-22	4.E-25	1.E-26
	2500	1.E-08	4.E-11	2.E-07	1.E-20	1.E-22	5.E-28	5.E-27	3.E-29	8.E-20	1.E-22	5.E-24
	5000	9.E-09	4.E-09	1.E-07	9.E-16	1.E-17	2.E-22	3.E-21	2.E-23	6.E-15	2.E-17	9.E-19
	10000	5.E-09	8.E-09	7.E-08	3.E-14	9.E-16	4.E-20	6.E-19	4.E-21	2.E-13	2.E-15	8.E-17

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